Quantification of Skeletal and Dental changes associated with the Forsus™ Appliance: A comparison of treatment effects observed during and following peak growth velocity.

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QUANTIFICATION OF SKELETAL AND DENTAL CHANGES ASSOCIATED WITH THE FORSUS™ APPLIANCE: A COMPARISON OF TREATMENT EFFECTS OBSERVED DURING AND FOLLOWING PEAK GROWTH VELOCITY.

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DEDICATION

This thesis and research is dedicated to my wife Angela. Without your hard work and support none of this would have been possible. I would also like to dedicate this to my children Alexander and Amelia for making every moment worth enjoying and inspiring me to work hard. I also would like to dedicate this to my parents for teaching me the value of hard work. I would also like to thank my Lord and Savior Jesus Christ for showing me the way in this residency and in life.

ACKNOWLEDGEMENTS

I would like to thank Dr Drew Fallis for all of his mentoring, patience, and guidance with this project; and for providing a much needed second set of eyes. I would also like to thank Dr Lisa Alvetro for providing all of the treatment and radiographs for this study.

“If I have seen further it is by standing on ye sholders of Giants”

Sir Isaac Newton

ABSTRACT

Intro: The goal of this thesis was to compare the skeletal and dental effects of the Forsus™ appliance observed on patients during peak growth versus post peak growth. The hypothesis was established that patients undergoing Class II treatment with a Forsus™ appliance during peak growth velocity would experience a larger degree of skeletal change than that observed in patients undergoing treatment with the same appliance, who have completed peak growth.

Methods: A sample of 54 Class II patients who were consecutively treated with the Forsus™ appliance was selected for this retrospective study. The subjects were placed into peak and post-peak growth groups based on their cervical vertebral maturation (CVM) status as determined from a lateral cephalogram taken at the initiation of Forsus™ therapy. Superimpositions of initial, pre-Forsus™, post- Forsus™, and final cephalometric radiographs were completed for each patient, allowing the measurement of observed changes during 3 treatment phases for each patient. Each cephalometric radiograph was manually traced, superimposed on successive time-points and subjected to Pitchfork analysis to demonstrate changes contributing to correction of Class II skeletal and dental relationships.

Results: Upon initial measurements; neither group was found to have a more severe skeletal Class II relationship. There were no significant differences between either group during Treatment Phase 1 of alignment and leveling with both groups showing a small initial increase in Class II severity. During Treatment Phase 2 with the Forsus ™

appliance, patients within the peak growth group showed a significantly higher mean apical base change and molar change towards Class II correction than patients who had completed peak growth. In addition, those patients also showed a significantly higher rate of apical base and molar change.

Both groups showed a significantly higher A-P change during Treatment phase 2 in comparison to Treatment phases 1 and 3. There were no significant differences between either group during Treatment Phase 3 (detail/finishing) which showed a minimal trend toward relapse.

Conclusions: Within the parameters of this study design, the results support that the use of the Forsus™ appliance during peak growth provides a more effective and efficient skeletal and molar change towards Class II correction.

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I. BACKGROUND AND LITERATURE REVIEW

A. Background

1. Class II malocclusion

Class II malocclusion, defined when the mesiobuccal cusp of the maxillary first molar is mesial to the mesiobuccal groove of the mandibular first molar, affects 23% of children, 15% of youths, and 13% of adults. Additionally, it is most prevalent in Caucasian populations of Northern European descent (Proffit et al. 2007, 1998) which according to the 2000 U.S. Census represents approximately 75% of the U.S. population. Due to this prevalence in the U.S, Class II is the most common A-P skeletal discrepancy, characterized by a large ANB angle and Wits appraisal, most often due to mandibular deficiency. Severity can range from an end-on molar relationship to a full step Class II, placing the mesiobuccal cusp of the maxillary first molar at the embrasure of the mandibular second premolar and first molar.

Other factors, often associated with Class II include a convex facial profile, protrusive maxilla, clockwise rotation of the mandible, poor chin projection, increased overjet, and labially inclined maxillary incisors

McNamara concluded that mandibular skeletal retrusion was the most common single characteristic of Class II patients (McNamara 1985) and with the exception of eliminating habits and preventing premature deciduous tooth loss, there are no known orthodontic treatments available to prevent Class II malocclusions (Bishara 2006). Therefore, correction of Class II malocclusions is a common orthodontic treatment objective.

2. Class II treatment

Numerous studies have evaluated growth modification utilizing various types of Class II correcting functional appliances (Bishara 2006, 1989, Burkhardt 2003, Chen 2002, Cozza, et al. 2002, de Almeida, et al 2002, Flores and Barnett 2009, Franchi 2011, Howe 1983, Huanca Ghislanzoni, et al 2012, Illing and Morris 1998, Liu et al. 2007, McNamara et al. 2001, 1990, 1985, Pancherz et al. 1991, 1986, 1985, 1982, 1981, 1979). Repositioning the mandible anteriorly can be achieved with functional appliances, but can only succeed if there is favorable condylar growth. Re-directing growth has shown to be significant towards Class II correction even if total growth was not increased (Wieslander and Lagerstrom 1979). Altering the eruption pattern of mandibular teeth more mesial by moving the mandibular denture base anterior can also be accomplished with functional appliances or Class II elastics; however, the long term stability of skeletal correction with elastics is questionable (Moore 1959). Additionally, it has been found advantageous to use appliances that control the vertical position of teeth to minimize mandibular rotation backward (Schudy 1964).

Correction of orthodontic problems associated with Class II can be achieved by several possible modalities: lengthening of the mandible, holding the position of the maxilla during mandibular growth, distal movement or holding the position of maxillary first molars, mesial movement of the mandibular first molars, as well as reduction of accompanying overjet via retroclination of maxillary incisors, and proclination of mandibular incisors. Vertical control is another important consideration to prevent down and back rotation of the mandible which would increase the amount of Class II correction required.

3. Superimpositions

Analysis of successive lateral cephalometric radiographs can provide a detailed account of the impact of Class II treatment. However, proper tracing should be performed from the beginning by hand tracing both time points side by side at the same time to ensure accuracy (Johnston 1996). Additionally, stable landmarks must be used in order for superimpositions to be accurate. If proper landmarks are selected, the superimpositions are comparable to those based on metallic implants. (Nielsen 1989). Only bodily translation of skeletal components can move teeth, remodeling of bone cannot; therefore, superimposition on stable internal landmarks provides a means to accurately assess tooth movement. The three main superimpositions used to analyze occlusal change are the cranial base, maxilla, and mandible (Johnston 1996). Stable landmarks for the cranial base superimpositions include the anterior wall of Sella Tursica, the greater wings of the Spheniod, the Cribriform Plate, the orbital roofs, and the inner surface of the Frontal bone (Bjork and Skieller 1983). In the maxilla, most studies have shown that a best fit registration on both the Zygomatic Process and the superior and inferior surfaces of the hard palate should be used (Nielsen 1989, Johnston 1996). In the mandible, implant studies have shown that regional superimpositions should use the mandibular canal, tooth buds without root development, and the internal bony architecture of the Symphysis (Bjork and Skieller 1983; Dibbets 1990). It has been shown that marking artificial references on the mandible in a longitudinal series of cephs is possible with superimpositions based on stable landmarks. These fiducial points can serve as replacement images for implants (Dibbets 1990).

The Pitchfork analysis is a method to represent measured anteroposterior change from growth and treatment following cephalometric superimposition. This can support comparisons of change between treatments and treatment phases regarding magnitude and source (skeletal vs. dental). It provides an organized method to summarize the various measurements of change that converge at the functional occlusal plane, defined as a line along the occlusal surface of the molars and premolars with the maxillary superimposition (Johnston 1996).

4. Growth status

Hand wrist film assessment of skeletal age first began in the early 1920's with the work of Gruelich and Pyle in the Radiographic Atlas of Skeletal Development of the Hand. (Greulich and Pyle 1959). Since the early 20th century, skeletal maturation has been determined from hand-wrist films where specific skeletal maturity indicators (SMI) of the phalanxes of the thumb, third finger, fifth finger and radius represent specific time intervals for skeletal maturation during adolescence.

The sequence for determining SMI begins by determining if the Adductor Sesamoid of the thumb has ossified. If this has not occurred then the width of the proximal and middle phalanxes of the third finger and width of the middle phalanx of the fifth finger are evaluated to determine if the patient is an SMI 1, 2, or 3 respectively. If ossification of Adductor Sesamoid of the thumb has occurred, then the patient is at or past SMI 4. Fusion of the distal phalanx of the third finger is then checked to determine if the patient is at or past SMI 8. If this fusion has not yet occurred, then capping of the distal phalanx of the third finger, capping of middle phalanx of third finger, and capping of the middle

phalanx of the fifth fingers are evaluated to determine if the patient is SMI 5, 6, and 7 respectively. SMI's 4 to 7 indicates the patient is in a period of rapid growth velocity (Moore 1959, Kopecky and Fishman 1993).

If fusion at the distal phalanx of the third finger is present then fusion of the proximal phalanx of the third finger, fusion of middle phalanx of the third finger and fusion of the radius are evaluated to determine if patient is SMI 9, 10, or 11 respectively (Fishman 1982).

However, disadvantages to this method include the additional radiation exposure for the hand wrist film and published literature demonstrates a consistent sex difference in skeletal age to the rate of facial growth (Smith 1980).

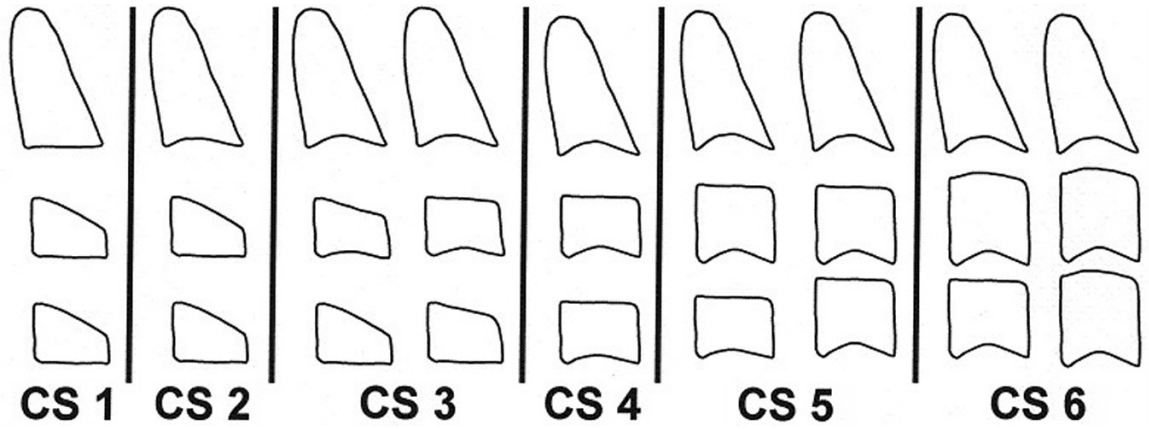
Currently the Cervical Vertebral Maturation Method has been used as an indicator to detect the optimal time to start treatment with functional appliances (Baccetti et al. 2005). One benefit to the patient with CVM is that it can be determined from the lateral cephalometric radiograph and eliminates additional radiation exposure encountered with the hand-wrist film.

The cervical vertebrae can be used with the same confidence as the skeletal maturity index (Kamal et al. 2006). However, the reproduction of specific CVM staging between individual clinicians has been shown to vary significantly in a recent study (Gabriel et al. 2009). The modified method is particularly useful when only the second through fourth vertebrae are visible. This method involves the analysis of the morphology of cervical vertebrae 2-6. At Cervical Vertebral Stage (CS) 1, all inferior vertebral borders are flat, at CS 2 a concavity is seen along the inferior border of C2 and the anterior height of the

vertebral bodies begins to increase. Both CS 1 and 2 indicate the patient has not yet reached peak growth.

AT CS 3, a concavity is seen at the inferior border of C3. At CS4, a concavity at the inferior border of C4 is seen along with initial concavity formation at the inferior borders of C5 and 6; additionally, the bodies of all of the cervical vertebrae are rectangular in shape. These two stages indicate that the patient is in peak growth status.

At CS 5, all of the concavities are well defined and the bodies are more square in shape. At CS 6, vertebral bodies show deeper concavities and a more vertically rectangular shape (Baccetti et al. 2002). (Figure 1). These two stages show that the patient is now past the peak growth status, although they may still have limited growth remaining.



STAGE	SHAPE	DESCRIPTION	PEAK GROWTH
CS 1	C3 & C4 TRAPEZOID	ALL LOWER BORDERS FLAT	AT LEAST 2 YEARS AWAY
CS 2	C3 & C4 TRAPEZOID	C2 CONCAVE IN 80% OF INDIVIDUALS	PEAK ABOUT 1 YEAR AWAY
CS 3	C3 MAY BE STARTING RECTANGULAR (HORIZONTAL)	C2 & C3 LOWER BORDERS CONCAVE	PEAK MANDIBULAR GROWTH
CS 4	C3 & C4 RECTANGULAR (HORIZONTAL)	ALL LOWER BORDERS CONCAVE	PEAK GROWTH ENDS OR DURING PREVIOUS YEAR
CS 5	ONE OF C3 OR C4 IS SQUARED IN SHAPE	ALL LOWER BORDERS CONCAVE	PEAK GROWTH ENDED ONE YEAR PRIOR TO THIS STAGE
CS 6	ONE OF C3 OR C4 IS RECTANGULAR (VERTICAL)	ALL LOWER BORDERS CONCAVE	PEAK GROWTH AT LEAST TWO YEARS PRIOR TO THIS STAGE

Figure 1: Developmental stages of Cervical Vertebrae (Baccetti et al. 2005).

The functional treatment of Class II skeletal disharmony depends strongly on the biological responsiveness of the condylar cartilage, which is related to the growth rate of the mandible. CS3 represents the ideal stage to begin functional jaw orthopedics, since the peak in mandibular growth will occur during or within a year after this observation (Baccetti et al. 2005).

5. Functional appliances:

Functional appliances have been used for many years to correct Class II malocclusion; however, the effect of functional appliances on mandibular growth remains somewhat controversial. The purpose of the functional appliance is based on the remodeling of the condylar process and in part the Glenoid Fossa (Stockli and Willert 1971) in a direction that will allow the mandible to lengthen. Effectiveness of the functional appliance strongly depends on biological responsiveness of the condylar cartilage (Petrovic et al. 1990). The majority of past functional appliances have been removable and thus dependent on patient compliance for effect. Consequently, results have a higher potential for inconsistency due to the need for patient cooperation. An implanted functional appliance study on beagles showed that a fixed functional appliance can significantly stimulate the growth of the mandible and avoid the unwanted movement of teeth which is frequently found in other functional appliances (Lin et al. 2008). In the 1980's, the Crown Herbst appliance was introduced as a more durable fixed functional appliance. Its active treatment time was relatively short and required little or no patient cooperation. Currently there are multiple functional appliances in use, some of which are able to be used in conjunction with fixed orthodontic appliances during

comprehensive treatment.

Treatment timing with a functional appliance can occur during pre-peak, peak, or post peak growth. Early treatment during pre-peak growth, which is typically a 2-phase treatment, has been shown to be effective in overjet reduction and only a small amount of skeletal change, but can result in an increase in patient self esteem (O'Brien et al. 2003). Studies evaluating treatment outcome between early treatment groups and adolescent groups have evaluated duration of treatment and final peer assessment rating (PAR) scores. It has been concluded that early Twin-block treatment followed by further adolescent treatment did not result in any meaningful long-term difference in treatment outcomes, but did result in increased cost and time to the patient (O'Brien et al. 2009). Additional studies have concluded that early treatment for Class II malocclusion is not normally justified (O"Brien 2009) and does not reduce the average time a child is in fixed appliances during the second phase of treatment (Tulloch et al. 2004). When considering treatment, one must consider the most consistent option with regards to timing in order to be the most efficient. Due to the great variation in response to early Class II treatment (Tulloch et al. 1997) it has been found to be no more effective to treat during pre-peak growth at an early age.

The ideal time to begin treatment with a functional appliance has been recommended to coincide with peak growth of the mandible (Baccetti et al. 2000). Skeletal effects from functional appliances have been most favorable when used during the ascending portion of the individual pubertal growth spurt (Malmgren et al 1987). It was shown in a Twin-block study that there was a greater skeletal contribution and increase in

mandibular length during or slightly after the onset of pubertal peak growth (Baccetti et al 2000).

Functional appliance therapy after peak growth has been shown to be more effective with dental changes than skeletal. Skeletal changes with the Herbst-multibracket treatment showed relapse, however the Class II occlusal correction remained stable (Bock 2011). When compared to early treatment groups, late treatment with the Herbst was equally efficient. However, one notable difference with later treatment was anchorage loss in the form of increased proclination of the lower incisors (Konik et al 1997).

6. Additional studies and their limitations

Previous studies with the edgewise Herbst appliance have shown significant skeletal effects in the correction of molar relation and overjet (Pancherz et al. 1991, 1986, 1985, 1982, 1981, 1979). These effects were reported to be in relation to the osseous adaptive changes in the Glenoid Fossa and condylar growth (VanLaeken and Martin 2006). Treatment with the X-bow appliance also resulted in favorable skeletal and dental changes in the direction of Class II correction, however decreased maxillary protrusion without mandibular advancement and an increase in vertical dimension were found (Flores and Barnett 2009). A study on Class II treatment with the Jasper jumper appliance showed that it was effective in correcting Class II in growing patients, however no distinction was made between patients in pre-peak vs. peak growth (Weiland 1995).

Another study comparing the Twin-block and Bionator appliances showed that both increased mandibular growth and were effective in correcting molar relationships, but the Twin-block was more efficient (Jena et al. 2006).

One recent study on the Forsus™ appliance compared effects in relation to Class II elastics, but no distinction was made between peak growth and non-peak growth subjects (Jones et al. 2008). It was determined only that the Forsus™ appliance was a good substitute for Class II elastics in non-compliant patients. On the other hand, another study showed that the Forsus™ appliance can improve the sagittal discrepancy and soft tissue profile convexity of patients with Class II malocclusion (Liu et al. 2007). Another Forsus™ study evaluated the dentoskeletal outcomes of the Forsus™ in combination with fixed appliances on Class II growing patients. These consecutively treated Class II patients were compared to untreated Class II controls. The study showed the Forsus appliance to be effective when combined with full fixed appliances in the correction of Class II malocclusion with a net reduction of 5.5mm overjet and a molar correction of 3.4mm. This correction is due to a combination of skeletal and dentoalveolar corrections. It also showed the Forsus™ to have a greater skeletal effect on the maxillary structures by restraining the sagital advancement of the maxilla, while most of the dentoalveolar modifications were found on the mandible (Franchi et al. 2011).

A thorough review of the literature on Class II correction reveals that many appliances have been studied; however, there have been wide variations in study designs with minimal description of the level of the participant's skeletal maturation stage. Therefore, there is minimal information available concerning the Class II treatment effects observed during these various stages of skeletal development.

This study was designed to compare the effectiveness and efficiency of Class II treatment with the Forsus appliance when treatment is initiated at different stages of skeletal maturation. Additionally, treatment effects during 3 specific orthodontic treatment phases (alignment/leveling, active Forsus treatment and final detailing/finishing) are compared to more-completely assess skeletal and dental changes associated with Forsus™ treatment.

II. OBJECTIVES

A. Overall Objective

The goal of this study was to quantify the skeletal and dental affects of the Forsus™ appliance on the dentofacial complex during non-extraction treatment of Class II malocclusions and determine if enhanced skeletal change occurs when treatment timing coincides with peak skeletal growth.

B. Specific Hypotheses

It is hypothesized that Forsus™ appliance treatment that is timed to include a patient's peak growth velocity will demonstrate a greater degree of skeletal change than that observed during treatment at stages following peak growth.

Forsus™ appliance treatment that is timed to include a patient's peak growth velocity will demonstrate a more efficient degree of Class II correction.

III. MATERIALS AND METHODS

A. Experimental Design

This retrospective study was conducted using lateral cephalometric radiographs from patients consecutively treated in the private practice of Dr. Lisa Alvetro (Alvetro Orthodontics: Sidney & Tipp City, OH) with the Forsus™ appliance. Each patient completed alignment and leveling of their dental arches (Treatment Phase 1), progressing in wire size to either 19x25 stainless steel or 19x25 Beta Titanium archwires before inserting the Forsus™ appliance (Treatment Phase 2). After removal of the Forsus™ a 0.017x0.025 Nickel Titanium archwire was placed on the mandibular arch to begin re-leveling. Box elastics for settling and E-chain for space closure were utilized as needed during detailing and finishing (Treatment Phase 3).

The orthodontic records of 54 subjects were evaluated. Patients were divided into two treatment groups based on cervical vertebral maturation status (designated as Cervical Stage or CS) as determined on the cephalometric radiograph taken at the time of Forsus™ appliance placement (T1). Patients were placed in groups rather than individual CS categories to reduce subjective error associated with designating a single specific stage, as previously reported (Gabriel et al. 2009). Patients in Group 1 (26 total) were considered to include peak growth and include CS 3 and 4. Patients in Group 2 (21 total) were considered post peak growth and include CS-5 and 6. In addition, 7 patients judged to be in CS-1 and 2 were included as a third group for descriptive comparison only.

Table 1: Pre-treatment cephalometric measurements for Group 1

Peak Growth	ANB	SN-MP
1	6	35
2	5	27
3	6	32
4	6	32
5	9	31
6	5	33
7	3	29
8	9	42
9	6	34
10	4	34
11	6	31
12	5	34
13	6	36
14	6	27
15	7	34
16	6	35
17	5	32
18	6	32
19	4	27
20	6	29
21	5	30
22	2	24
23	6	29
24	5	37
25	4.5	39

Table 2: Pretreatment cephalometric measurements for Group 2

Post Peak Growth	ANB	SN-MP
1	4	34
2	5	25
3	7	38
4	3	33
5	4	41
6	6	39
7	8	40
8	4	27
9	5	34
10	4	41
11	7	43.5
12	7	34
13	6	28
14	4	30
15	5	34
16	5	40
17	7	45
18	5	32
19	4.5	32
20	6	35
21	4	25
22	3	25

All lateral cephalometric radiographs were captured digitally on an Orthoceph OC100D (Instrumentarium, Milwaukee, Wisconsin) from Alvetro Orthodontics: a private orthodontic practice in Sidney, Ohio. Initial, pre- Forsus™ post- Forsus™ and final cephalometric films were recorded with teeth in maximum intercuspation for each patient. Each film was printed on photo quality paper in 1:1 format and consecutively hand-traced on acetate film with a 0.7mm mechanical pencil by the primary investigator (DS) (Figure 2).

Serial tracings of the patients were superimposed to determine changes from initial, pre-Forsus™ post- Forsus™ and final treatment. Landmarks used for superimposition of the cranial base included Planum Sphenoidum, Cribriform plate of the Ethmoid bone, and midpoint of curvature of the greater wing of the Sphenoid with Sphenoid plane-Cribriform plate contour. A reference landmark, W-point or “wing point” was marked at the intersection of all cranial base landmarks. Landmarks used for regional changes in the mandible include the inner cortex of Symphysis, 3rd molar crypt (if present), and the Inferior Alveolar Nerve canal. The landmarks for regional changes in the maxilla included the anterior curvature of the hard palate and Key Ridge. For consistency, the most distal of any double landmark, the outermost border of the maxilla, and the most superior line of the inferior border of the mandible were traced (Figure 2).

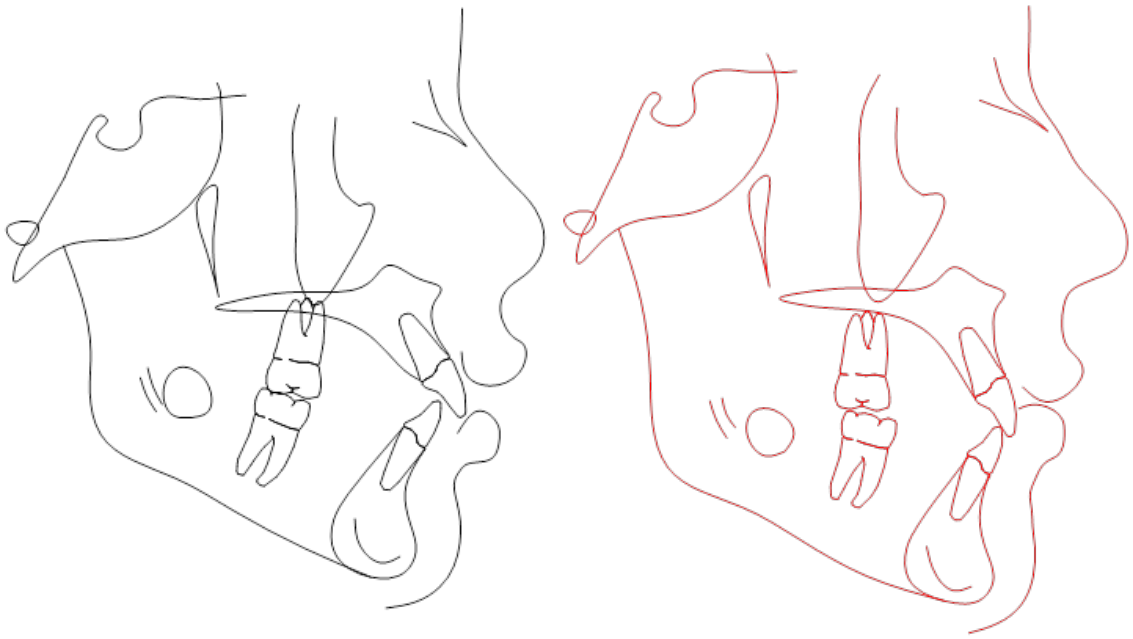


Figure 2: Consecutive time points hand traced on acetate with a 0.7mm mechanical pencil.

Tooth templates were created for each case based on the films in each series that provided the best anatomic view and multiple films were used to create an accurate template of the patient's molars and incisors for subsequent tracings. The long axis was marked on each tooth template to aid in accurate measurement. Fiducial lines (parallel to cranial base, palatal plane, and mandibular plane) and a fiduciary point (D-point) internal to the Mandibular Symphysis were then placed on the initial tracing. A constructed line from Sella through D-point was also added (Gnathion-Sella) to the initial tracing for comparison of rotational change of the mandible relative to cranial base (Figure 3).

Fiducial lines were transferred from the initial time point tracing upon each respective superimposition. D-point was transferred to the progress tracing via the regional mandibular superimposition. The progress tracing Gn-S line was created from Sella to the transferred D-point as previously reported (Johnston 1996) (Figures 4-6).

A mean constructed functional occlusal plane was derived on the maxillary superimposition by drawing a line bisecting the angle formed by the occlusal planes on the superimposed tracings (Figures 7 and 8).

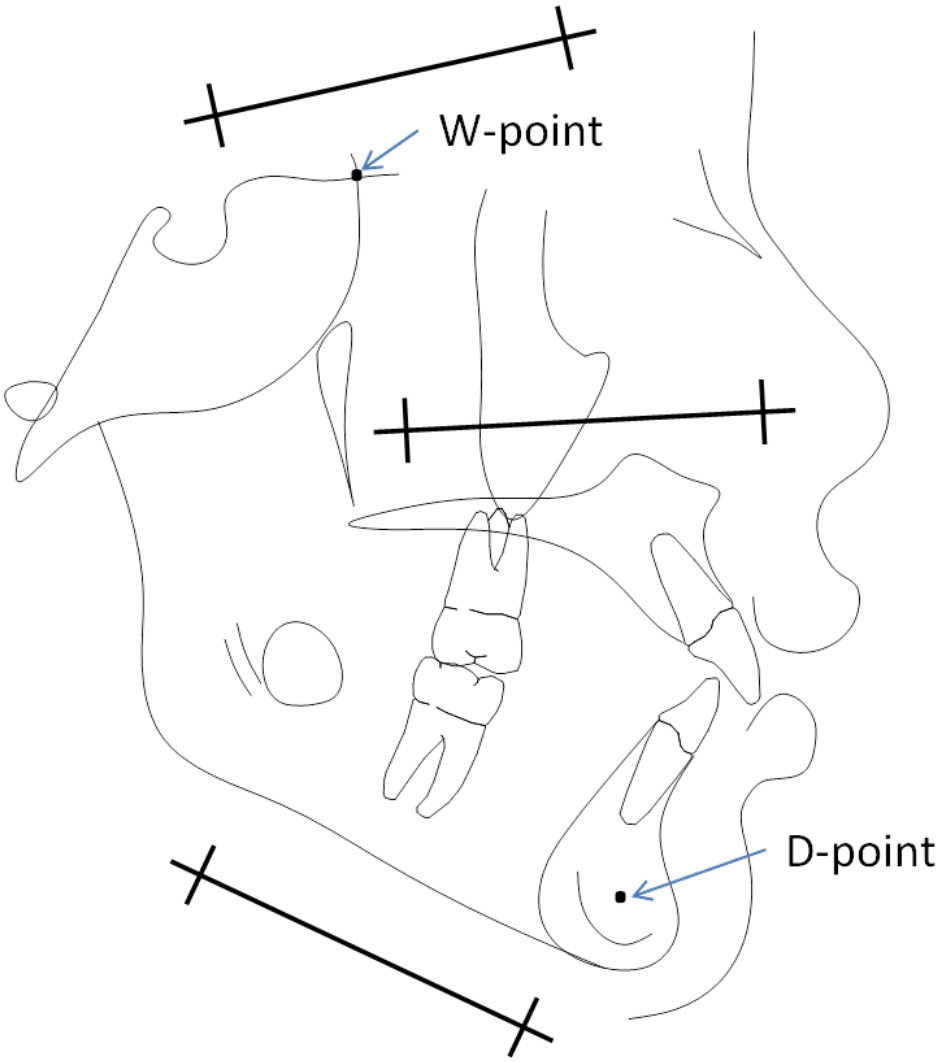


Figure 3: Initial tracing; fiducial lines, D-point (a fiducial point along Gn-S at the internal symphysis), and W-point (marked the intersection of cranial base landmarks.

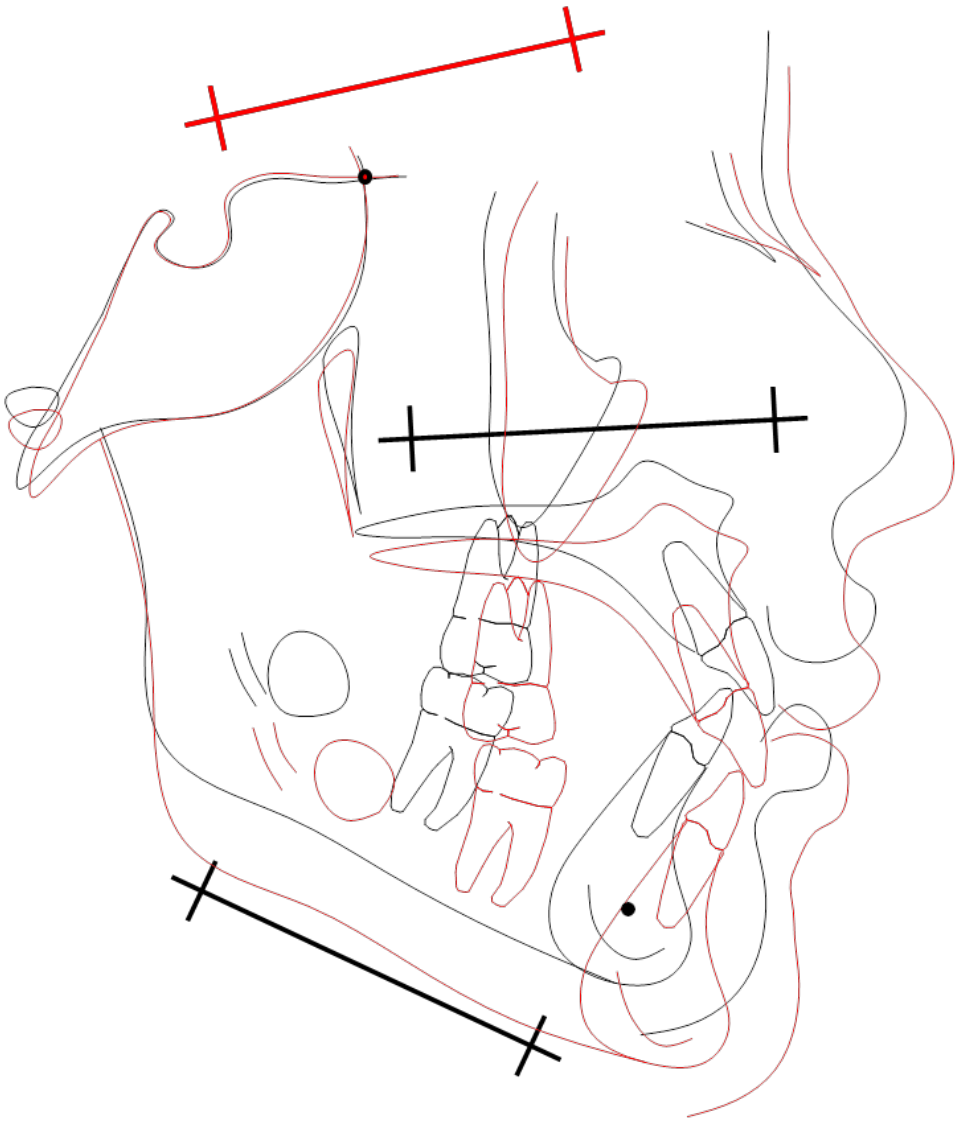


Figure 4: Cranial base superimposition: Cranial base fiducial line and W-point transferred to progress tracing.

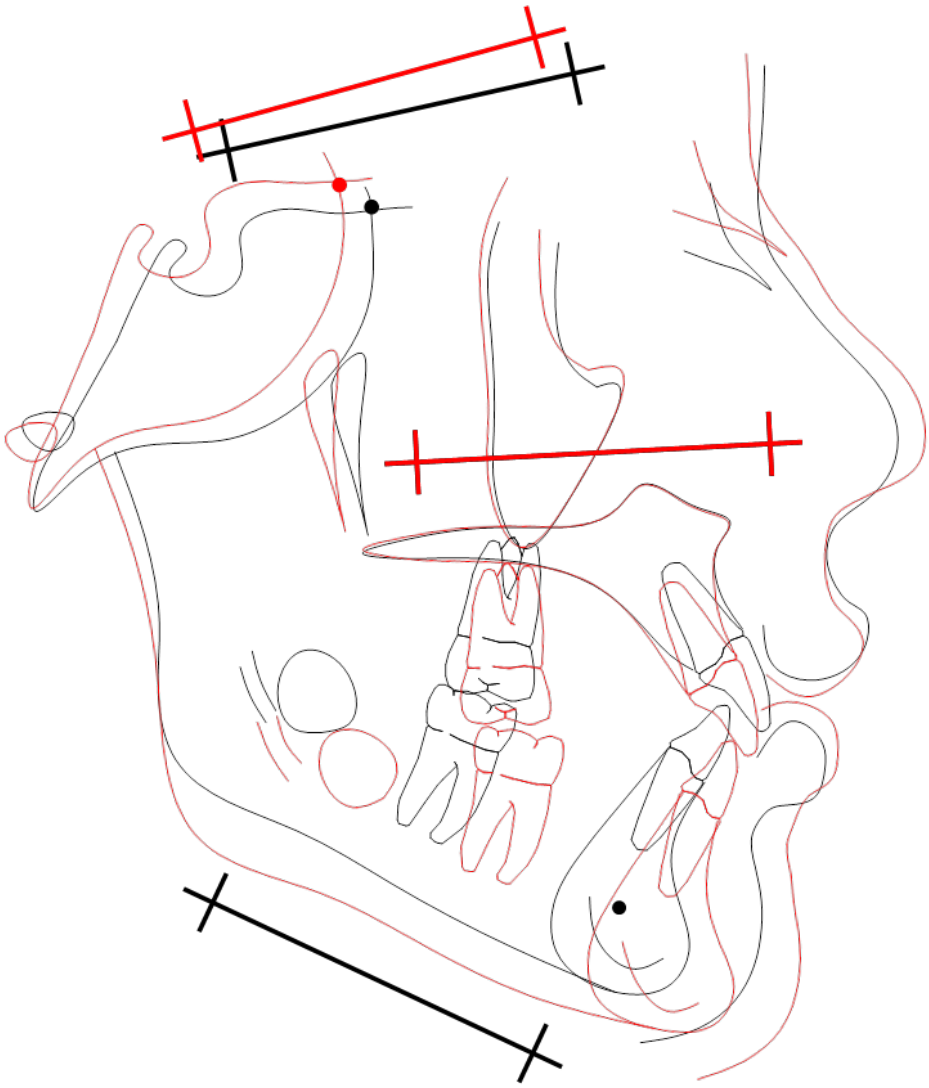


Figure 5: Maxillary superimposition: Maxillary fiducial line is transferred to the progress tracing.

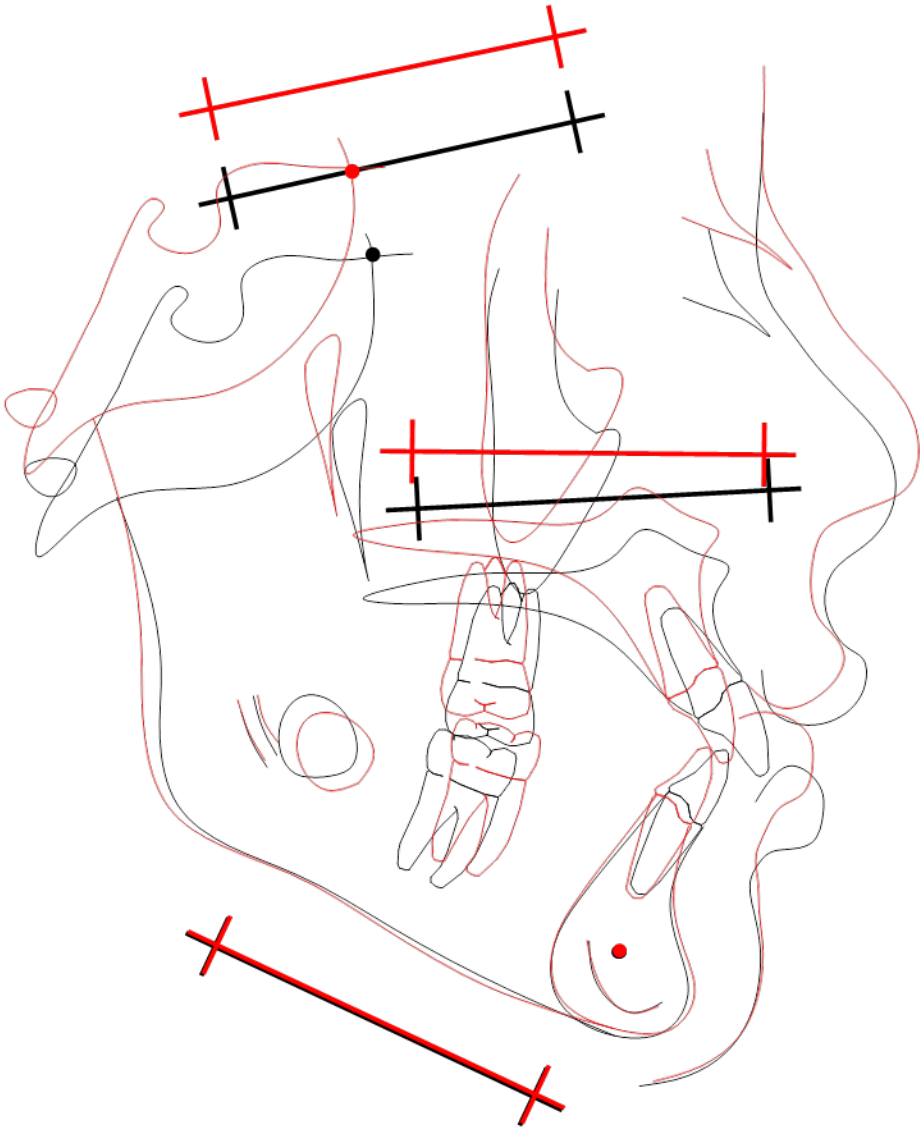


Figure 6: Mandibular superimposition: mandibular fiducial line and D-point are transferred to progress tracing.

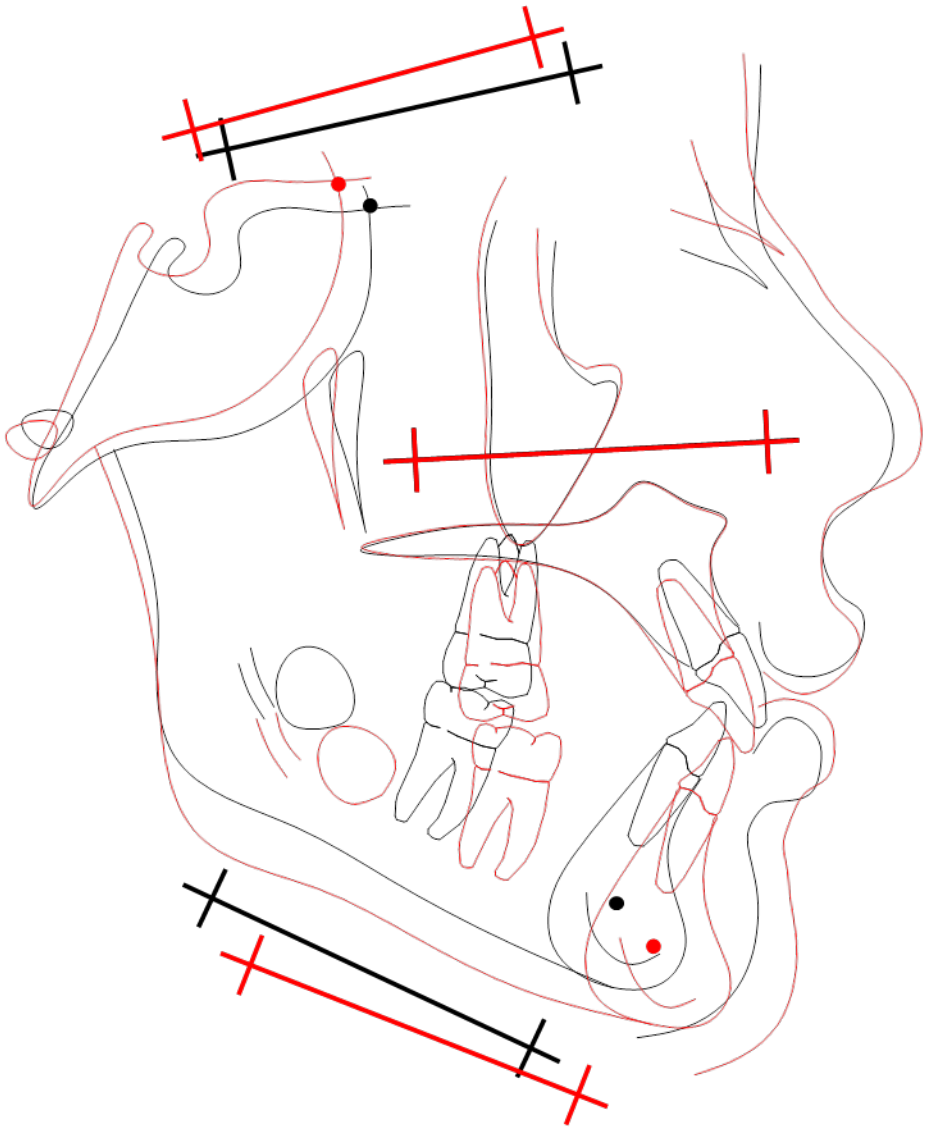


Figure 7: Once all fiducials were transferred, tracings were placed back to the maxillary superimposition to determine constructed occlusal plane.

(note: functional occlusal plane was determined on each tracing by drawing line from occlusion of first molars through the premolars.

*For demonstration purposes of the superimposition technique, the functional occlusal planes were initially omitted from the examples).

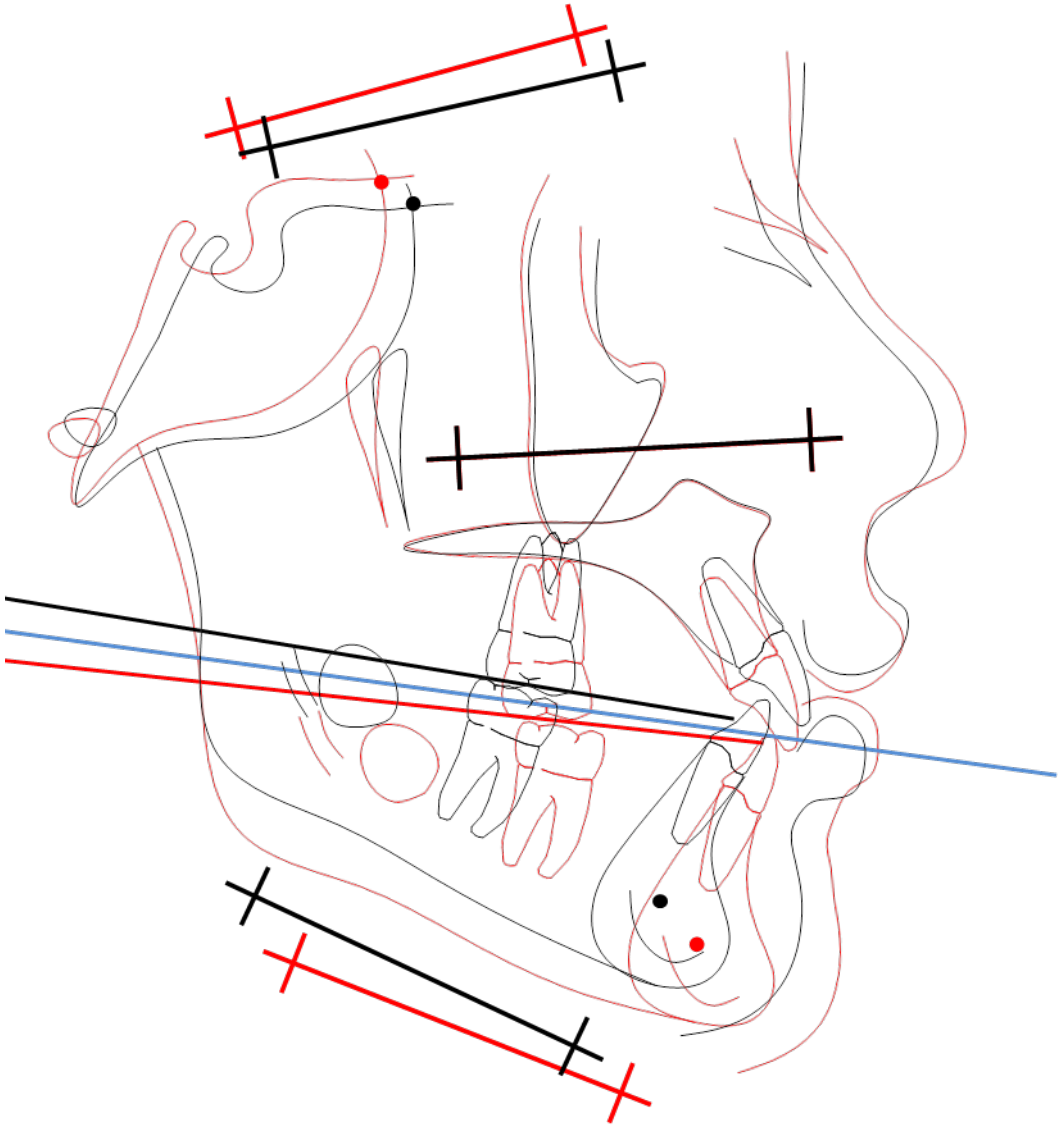


Figure 8: Constructed mean functional occlusal plane (blue) derived by bisecting the angle of the functional occlusal planes of both tracings.

The Pitchfork analysis was used to summarize the skeletal and dentoalveolar changes between each time point (Johnston 1996). This analysis uses cephalometric superimposition to measure physical movement of all first molars and central incisors relative to their skeletal bases, as well as displacement of the maxilla and mandible relative to the cranial base (Jena et al 2006).

To determine skeletal changes, lines from initial and progress W-point and D-point were drawn perpendicular to constructed occlusal plane from the maxillary superimposition. The net A-P change of the maxilla was determined by the distance measured between the lines from initial and progress W-points. The apical base change was determined by the distance measured between the lines from initial and progress D-points (Figure 9). Mandibular change was determined simply by subtracting the apical base change from the maxillary change (Johnston 1996).

For dental changes, lines were made from the mesial surfaces of first molars and the incisal edges of the incisors perpendicular to the occlusal plane. The distance measured between the initial and progress lines provided the net A-P change of each molar and incisor. Angulation changes of the long axis of teeth were also measured. Changes in the maxillary teeth were measured on the maxillary superimposition while changes in the mandibular teeth were measured on the mandibular superimposition (Figures 10 and 11).

Apical base change was added to the dental changes for the total A-P change from treatment as outlined in the original report of method (Johnston 1996). Positive values were given to movements that corrected Class II or reduced overjet (distal maxillary, mesial mandibular, counterclockwise rotation of mandible, maxillary incisor

retroclination, and mandibular incisor proclination). Negative values were given to measurements that increased the Class II relationship or increased the overjet (mesial maxillary, distal mandibular, clockwise rotation of mandible, maxillary incisor proclination, and mandibular incisor retroclination).

Since each Pitchfork represented changes between two time-points, 3 Pitchforks were constructed to demonstrate changes observed in each patient. The total A-P changes from each Pitchfork were calculated, means established and mean measurements compared between all time-points.

Rotational change of the mandible and occlusal plane were measured on the cranial base superimposition. The measured angle between initial and progress S-Gn determined the amount of mandibular rotational change relative to the cranial base. The measured angle between initial and progress occlusal plane determined the net occlusal plane rotation. Magnitude and direction (clockwise or counterclockwise) was recorded along with each pitchfork (Figure 12).

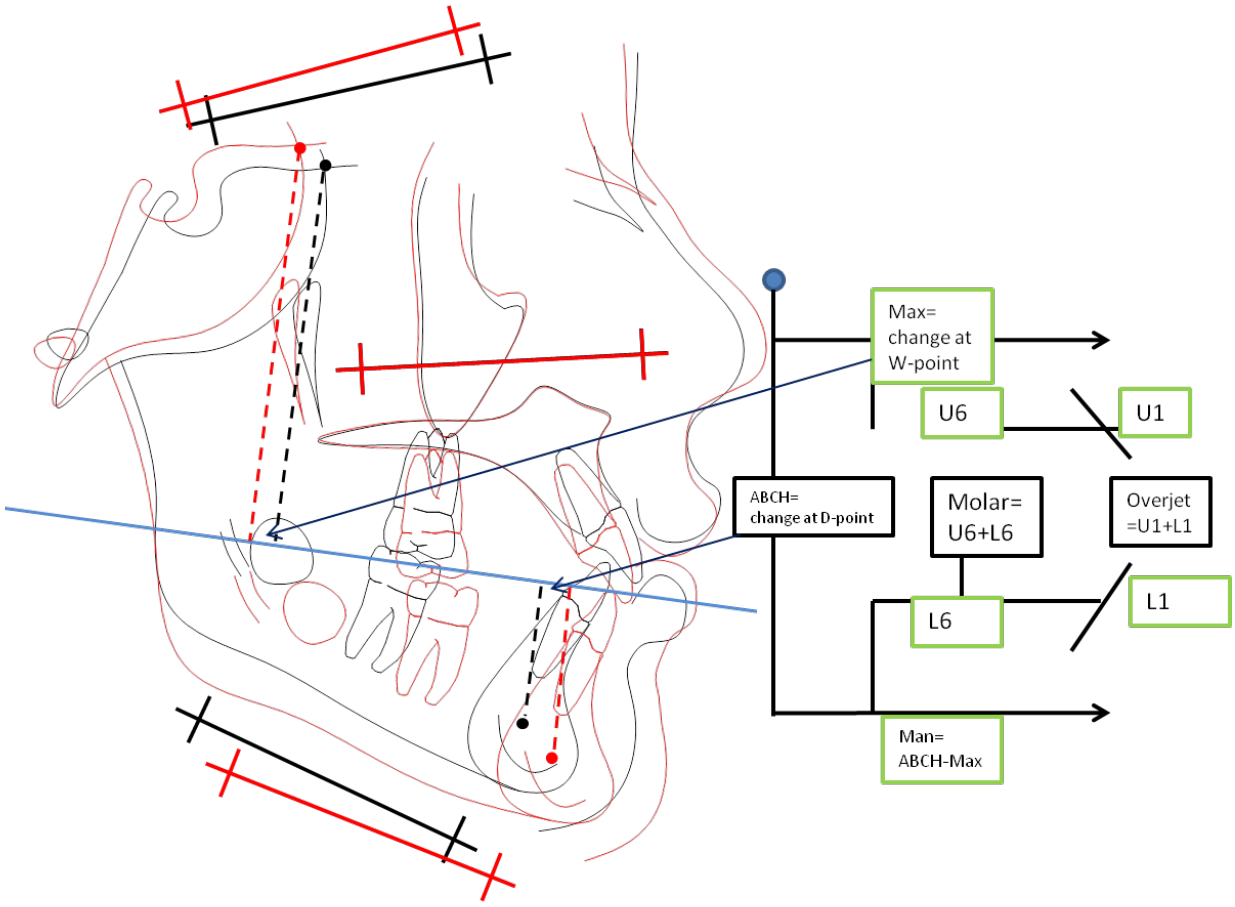


Figure 9: To determine skeletal changes, lines from initial and progress W-point and D-point were drawn perpendicular to constructed occlusal plane from the maxillary superimposition.

*The distance between the W-points determines the net A-P change in the maxilla, while the distance between the D-points determines the apical base change.
The net A-P mandibular change can be derived by subtracting Max from ABCH.

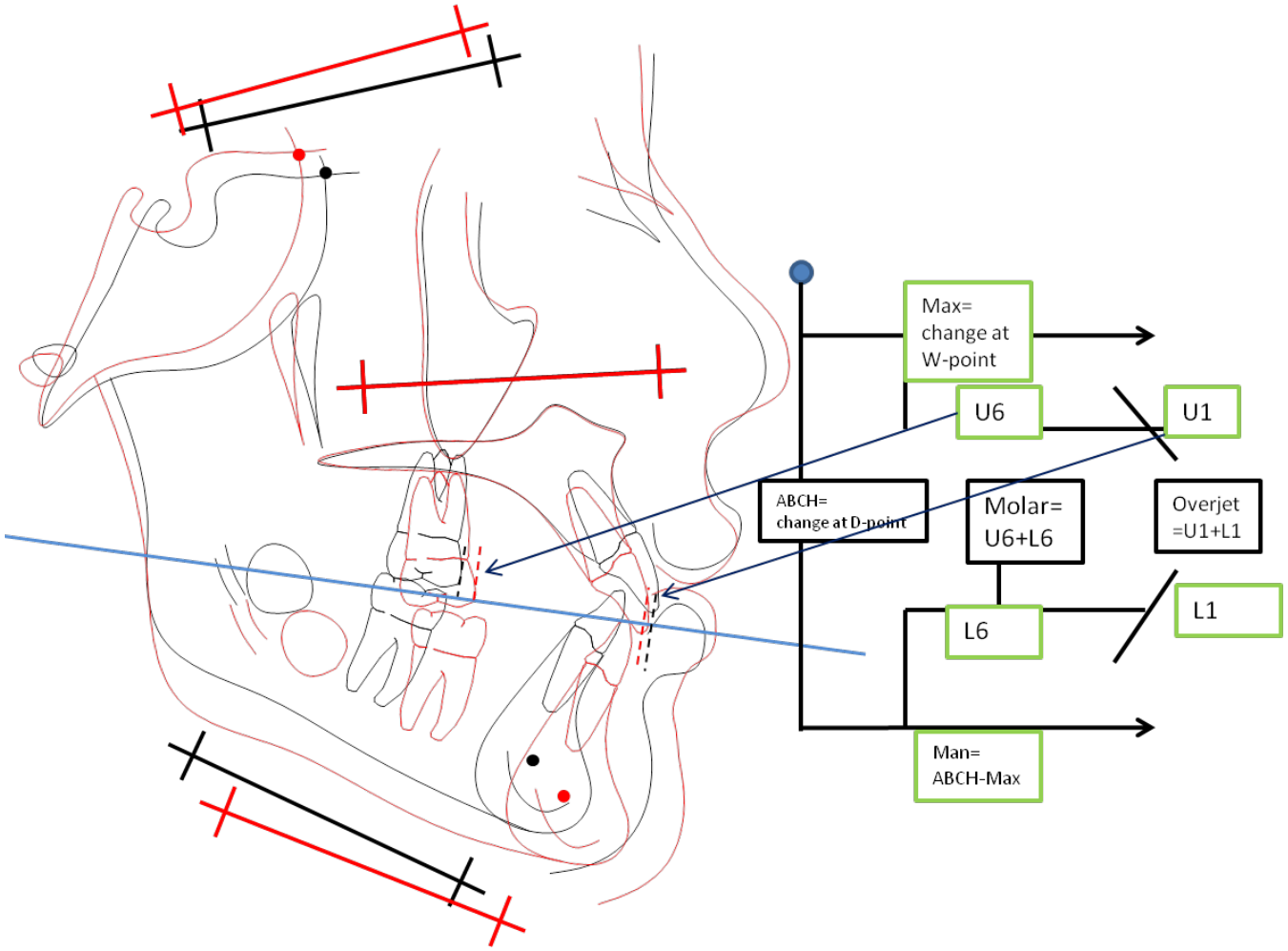


Figure 10: For maxillary dental changes, lines from the mesial of each molar and incisal edge of each incisor were made perpendicular to constructed occlusal plane.

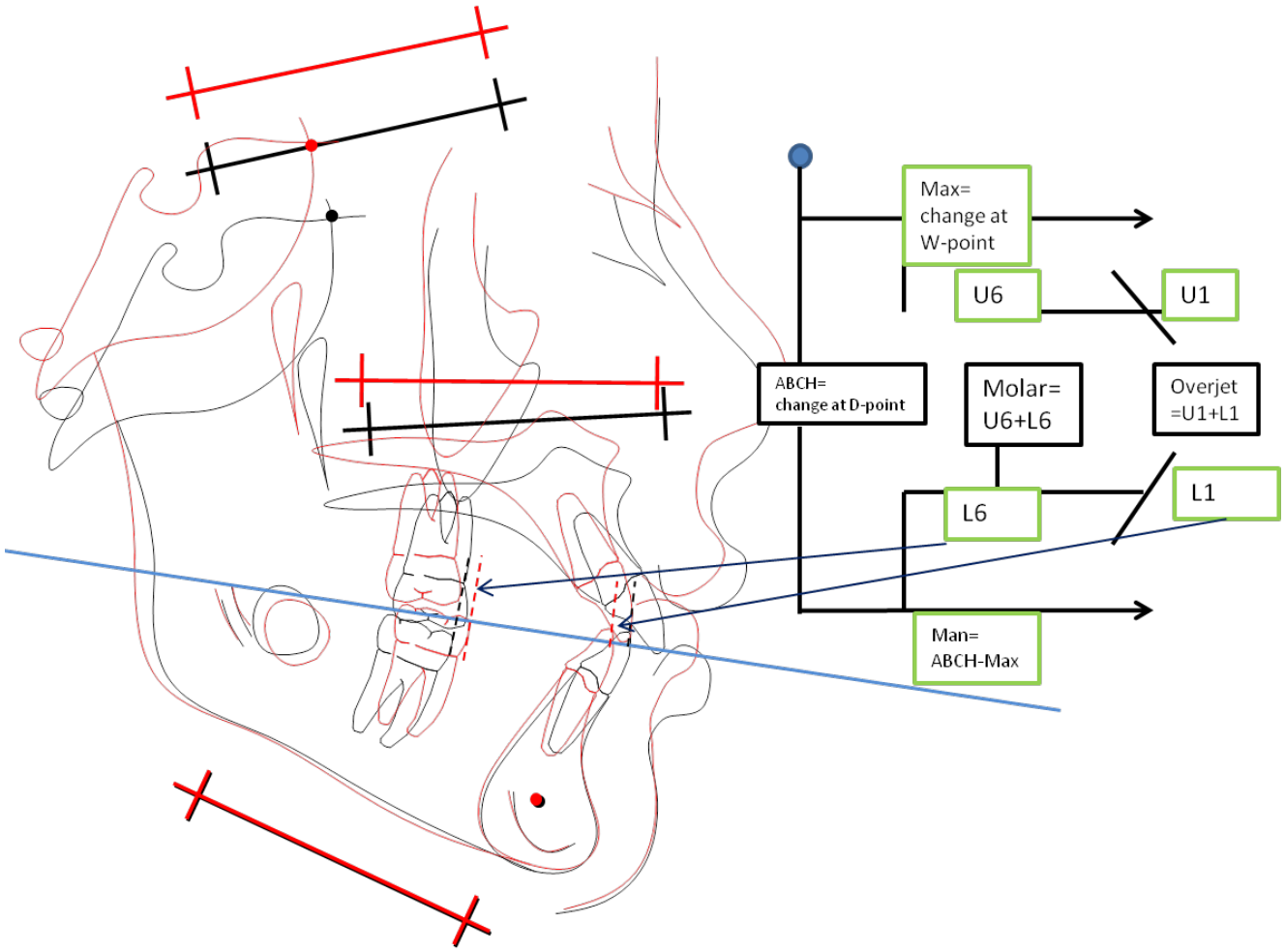


Figure 11: For mandibular dental changes, lines from the mesial of each molar and incisal edge of each incisor were made perpendicular to constructed occlusal plane.

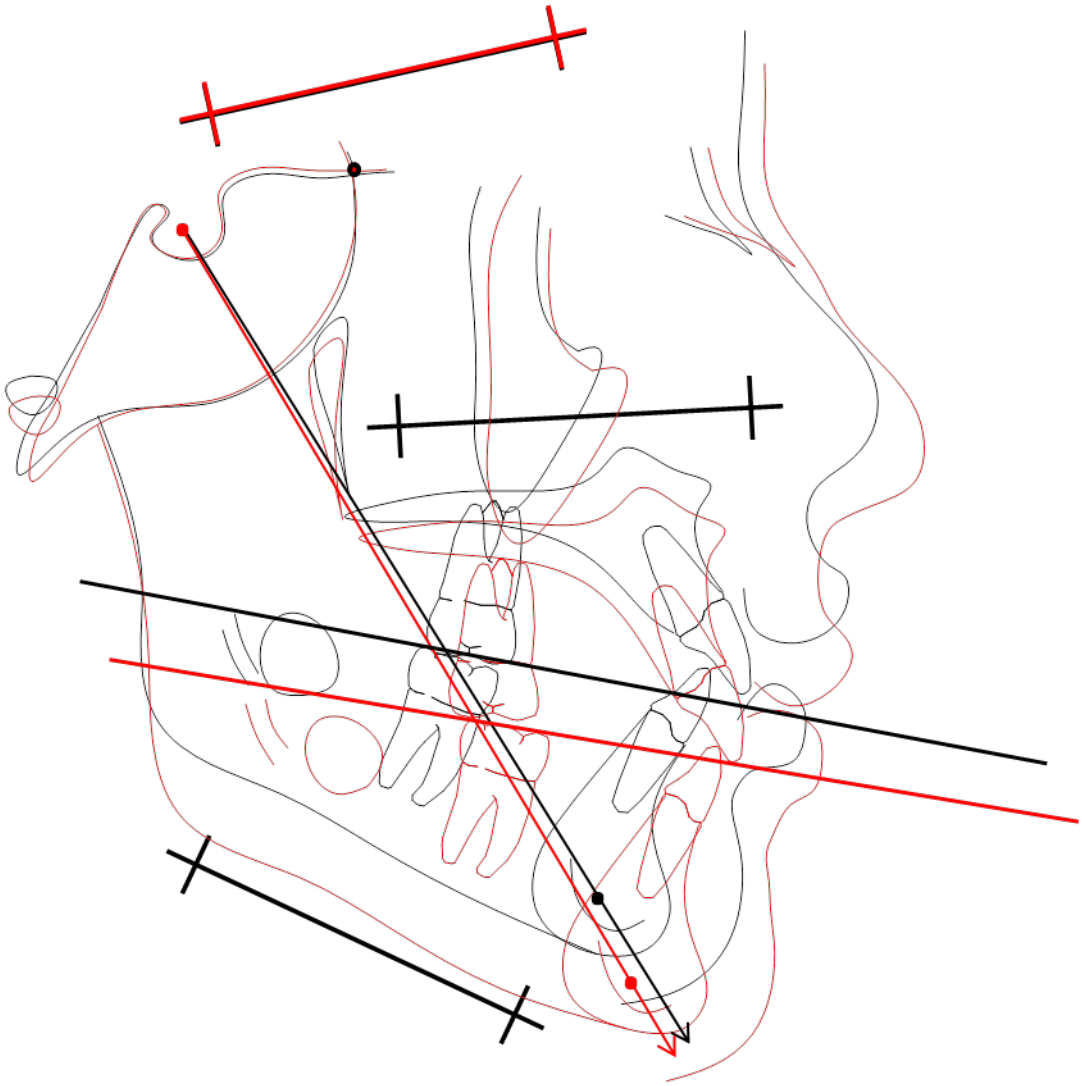


Figure 12: S-Gn change and occlusal plane change were measured on the cranial base superimposition.

B. Statistical Management of Data

The sample sizes of 25 and 22 provided 80% power to detect a moderate effect size (0.77 std deviations) difference between means when testing with a Student's t-test at the alpha level of 0.05 (NCSS PASS 2002).

Mean ANB and MP-SN measurements of Groups 1 and 2 were compared to assess the likeness of the two groups, as it pertained to the severity of the Class II skeletal relationship. These means were compared with unpaired t-tests, with the level of statistical significance set at $p \leq 0.05$.

Data were analyzed with a paired Student's t-test to compare individual mean changes in each measurement category between Phase 1 (T_0-T_1), Phase 2 (T_1-T_2), and Phase 3 (T_2-T_3) within each group. Mean changes measured at each treatment phase were compared between the two groups with unpaired t-tests.

Rates of change were calculated for the Phase 2 (T_1-T_2)/Forsus™ treatment phase of each group and then rate differences between Groups 1 and 2 were compared with unpaired t-tests to determine statistically significant differences.

RESULTS:

Mean measurements for initial (T_0) ANB and MP-SN angles are reported in Tables 3 and 4 for the two groups. A statistical comparison of these means with an unpaired t-test at a significance level of $p \leq 0.05$ revealed no statistical difference for ANB ($p = 0.33$), or SN-MP angle between the two groups ($p = 0.11$).

Table 3- Initial ANB measurements at T_0

Category	Group 1 ANB	Group 2 ANB
Mean	5.58 º	5.16 º
Std Dev	1.48 º	1.41 º

Table 4- Initial SN-MP measurements at T_0

Category	Group 1 SN-MP	Group 2 SN-MP
Mean	31.92	34.34
St Dev	4.17	6.07

Mean changes were calculated for each treatment phase (T_0-T_1, T_1-T_2 and T_2-T_3) in both treatment groups, as illustrated in Pitchfork and graphic format in Figures 13- 20 . As illustrated in the figures, skeletal or dental movements that contributed to Class II correction were illustrated in “black” font and those movements that worsened the Class II correction were illustrated in “red”.

GROUP 1 (Peak Growth) – Treatment Phase 1 (T_0 –T_1)

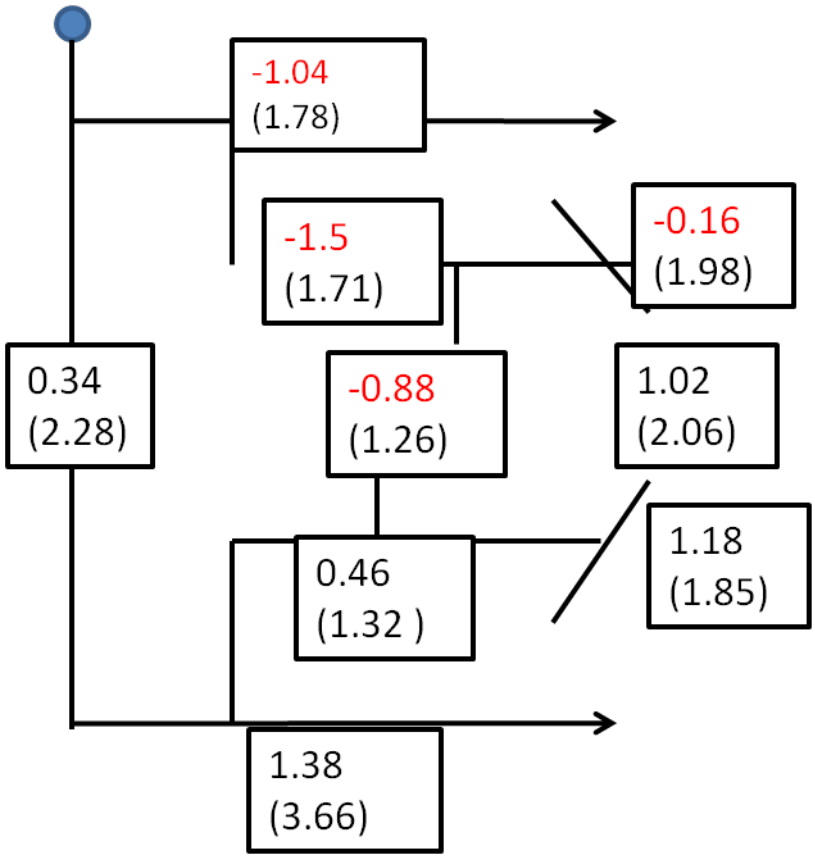
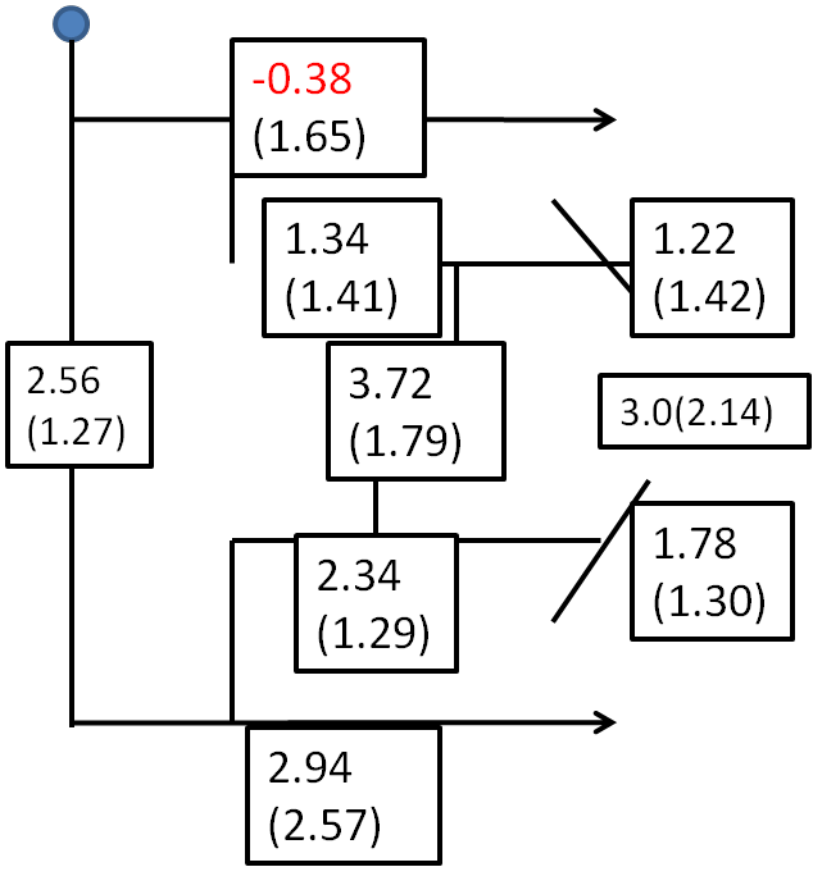


Figure 13- Group 1 Mean Changes & (Standard Deviations) from Treatment Phase 1
*Improvements toward Class I or change toward reduction in Overjet illustrated as + (Black) and worsening of Class II or change toward increase in Overjet illustrated as – (Red).

Category	S – Gn	Occlusal Plane	U1	U6	L1	L6
Mean (SD)	-0.92° (1.12)	+2.3° (3.42)	-2.88° (8.17)	-4.12° (4.18)	+2.94° (5.22)	-3.98° (3.58)

As illustrated in Figure 13, during Treatment Phase 1 of comprehensive orthodontic treatment ($T_0 – T_1$), the patients in Group 1 (Peak Growth Group) showed mean skeletal changes that worsened the Class II malocclusion by continued forward growth of the Maxilla and downward/ backward rotation of the Mandible. The dental Class II molar relationship worsened by forward movement and tipping of the Maxillary molar and incisor as well as distal uprighting of the Mandibular molar (L6 angle change of -3.98°). The mean apical base change contributed to very slight Class II correction, due to positive Mandibular growth that exceeded Maxillary growth; whereas, the overjet improved due to forward movement and proclination of the Mandibular incisor (1.18mm/2.94°) and forward rotation of the occlusal plane.

GROUP 1 (Peak Growth) – Treatment Phase 2 (T_1 –T_2)



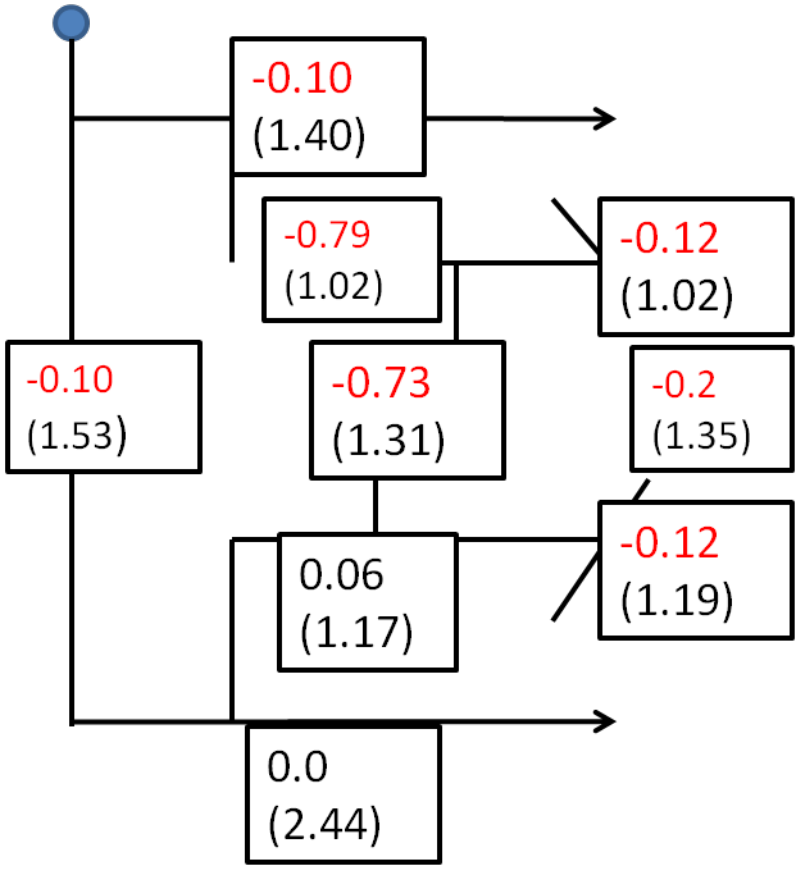
Category	S – Gn	Occlusal Plane	U1	U6	L1	L6
Mean (SD)	0.40º (1.19)	-2.64º (3.16)	4.44º (4.85)	3.81º (2.25)	6.18º (3.07)	3.92º (3.75)

Figure 14- Group 1 Mean Changes & (Standard Deviations) from Treatment Phase 2
*Improvements toward Class I or change toward reduction in Overjet illustrated as + (Black) and worsening of Class II or change toward increase in Overjet illustrated as – (Red).

The mean changes from Treatment Phase 2, the Forsus™ treatment phase, are illustrated in Figure 14. As demonstrated, all measurements were positive and contributed toward correction of the Class II skeletal and dental relationships with the

exception of a very slight forward movement of the Maxilla and backward (upward in back) rotation of the occlusal plane.

GROUP 1 (Peak Growth) – Treatment Phase 3 (T_2 –T_3)

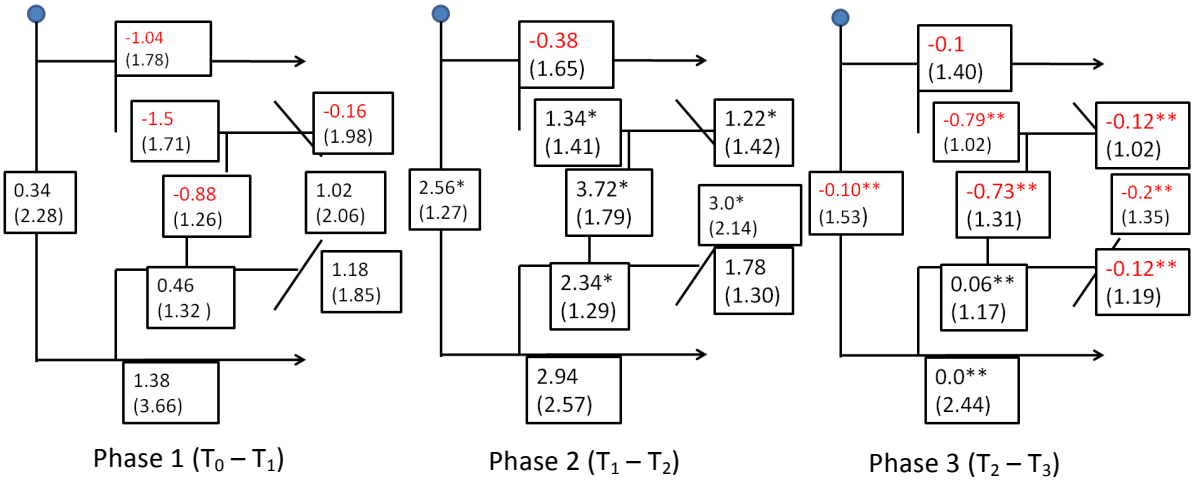


Category	S – Gn	Occlusal Plane	U1	U6	L1	L6
Mean (SD)	-0.42° (1.26)	0.96° (2.86)	-1.2° (3.53)	-0.58° (4.94)	-1.8° (4.01)	-1.58° (3.58)

Figure 15- Group 1 Mean Changes & (Standard Deviations) from Treatment Phase 3
*Improvements toward Class I or change toward reduction in Overjet illustrated as + (Black) and worsening of Class II or change toward increase in Overjet illustrated as – (Red).

Mean changes in Treatment Phase 3, the final finishing phase of comprehensive orthodontic treatment are represented in Figure 15 and correspond to the effects observed following the removal of the Forsus™ appliance. As demonstrated, measured changes represent very minor relapse movements of the effects seen during the Forsus™ treatment phase, with the exception of a slight forward movement of the Mandibular molar.

Figure 16 demonstrates within Group 1, the mean changes observed during each successive treatment phase, which were compared via a paired Student t-Test with the level of significance established at $p \leq 0.05$. A comparison of changes observed during Treatment Phase 1 to those observed during Treatment Phase 2 (Forsus™) revealed statistically significant differences in all measurements with a few exceptions.
Apical base change was significantly different; however, the individualized components (Maxilla and Mandible) that contributed to apical base change were not. The maxilla had less forward movement and the mandible had twice the forward movement in Treatment Phase 2 compared to Treatment Phase1; however, insignificant statistically. There was also no significant difference in lower incisor position between the two phases of treatment.
A comparison of changes observed between Treatment Phase 2 and Treatment Phase 3 revealed significant differences in all measurements except Maxillary and S-Gn changes.



Phase 1 ($T_0 - T_1$) Phase 2 ($T_1 - T_2$) Phase 3 ($T_2 - T_3$)

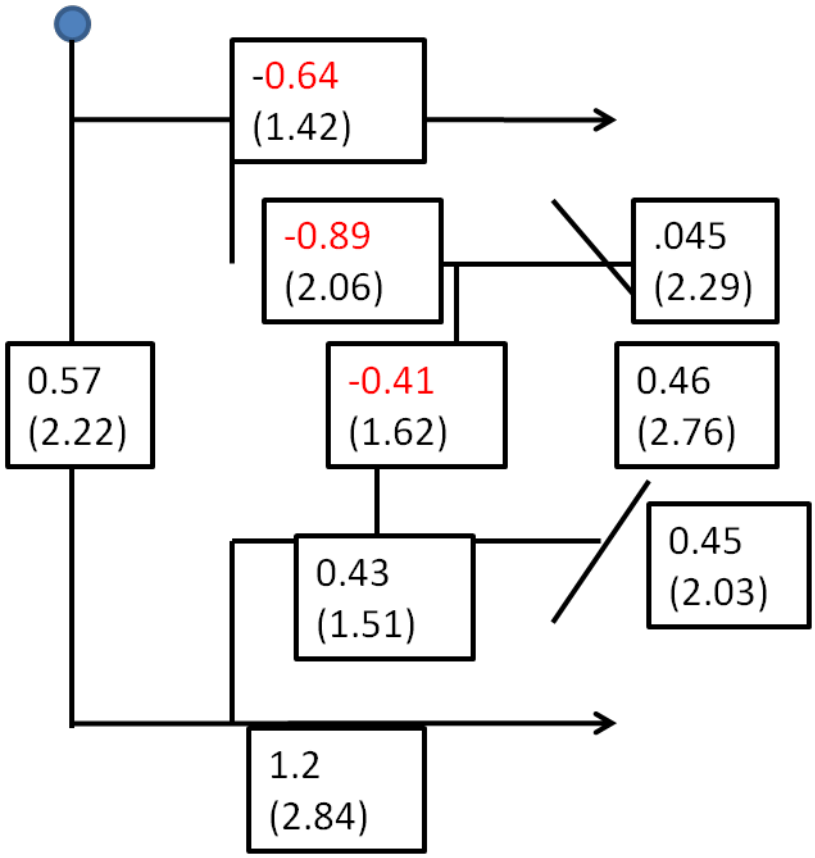
	S – Gn	Occlusal Plane	U1	U6	L1	L6
Phase 1	**-0.92° (1.12)**	**+2.3° (3.42)**	**-2.88° (8.17)**	**-4.12° (4.18)**	**+2.94° (5.22)**	**-3.98° (3.58)**
Phase 2	**0.40° (1.19)***	**-2.64° (3.16)***	**4.44° (4.85)***	**3.81° (2.25)***	**6.18° (3.07)***	**3.92° (3.75)***
Phase 3	**-0.42° (1.26)**	**0.96° (2.86)****	**-1.2° (3.53)****	**-0.58° (4.94)****	**-1.8° (4.01)****	**-1.58° (3.58)****

Figure 16- Comparison of Group 1 Treatment Phases

* denotes statistically significant difference between Phase 1 and 2 at $p \leq 0.05$ level.

** denotes statistically significant difference between Phase 2 and 3 at $p \leq 0.05$ level.

GROUP 2 (Post Peak Growth) – Treatment Phase 1 (T_0 –T_1)



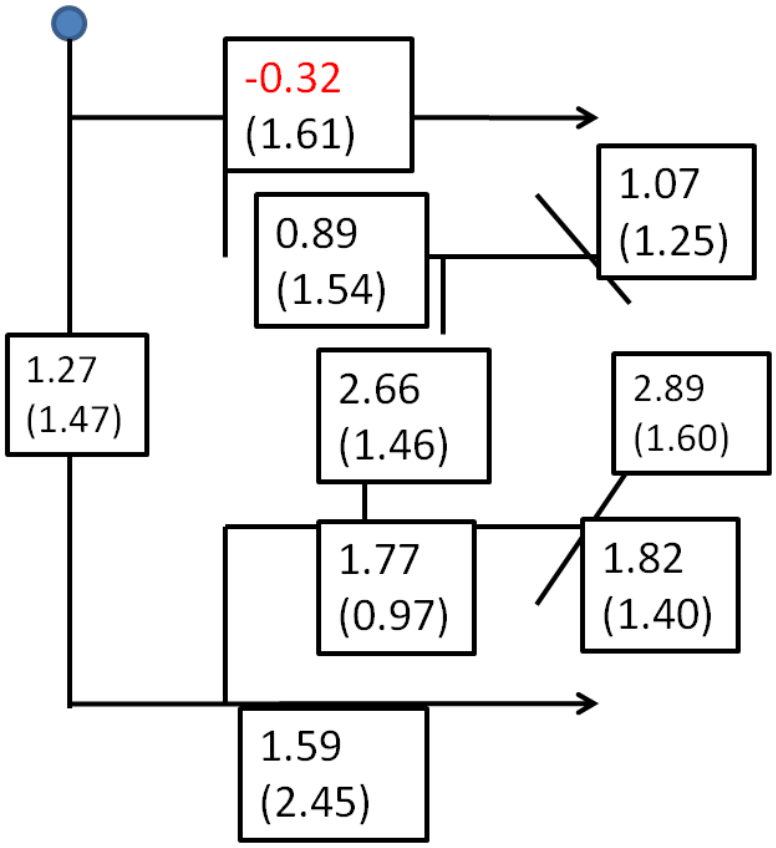
Category	S – Gn	Occlusal Plane	U1	U6	L1	L6
Mean (SD)	-0.73° (1.09)	+1.98° (2.36)	-0.36° (9.31)	-2.39° (4.28)	+1.14° (5.15)	-1.98° (4.39)

Figure 17- Group 2 Mean Changes & (Standard Deviations) from Treatment Phase 1
*Improvements toward Class I or change toward reduction in Overjet illustrated as + (Black) and worsening of Class II or change toward increase in Overjet illustrated as – (Red).

The patients in group 2 (Figure 17) showed mean changes that worsened the Class II malocclusion skeletally with continued forward growth of the Maxilla and downward/backward rotation of the Mandible. Mean dental changes that worsened the Class II included forward movement and mesial tipping of the Maxillary molar, Maxillary incisor proclination, and distal uprighting of the Mandibular molar (-2.39°).

Patients in group 2 also showed mean changes toward very slight improvement of the Class II with mean apical base improvement due to continued positive Mandibular growth exceeding that of Maxillary growth. The overjet improved by mesial movement and proclination of the Mandibular incisor (6.4°), along with slight distal movement and uprighting of the Maxillary incisor (4.0°).

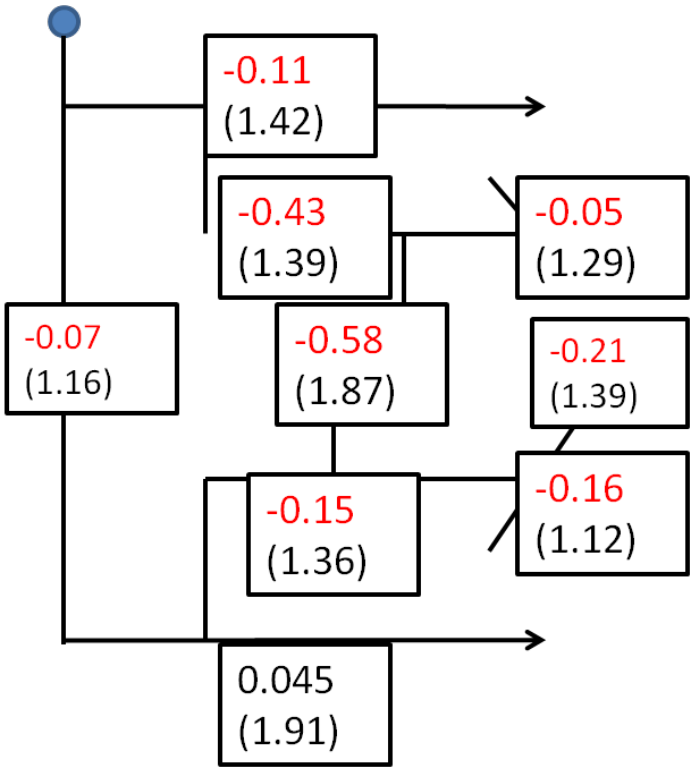
GROUP 2 (Post Peak Growth) - Treatment Phase 2 (T_1 –T_2)



Category	S – Gn	Occlusal Plane	U1	U6	L1	L6
Mean (SD)	0.43° (0.90)	-2.7° (3.55)	4.18° (3.92)	2.72° (3.43)	6.4° (4.11)	3.75° (3.48)

Figure 18- Group 2 Mean Changes & (Standard Deviations) from Treatment Phase 2
*Improvements toward Class I or change toward reduction in Overjet illustrated as + (Black) and worsening of Class II or change toward increase in Overjet illustrated as – (Red).

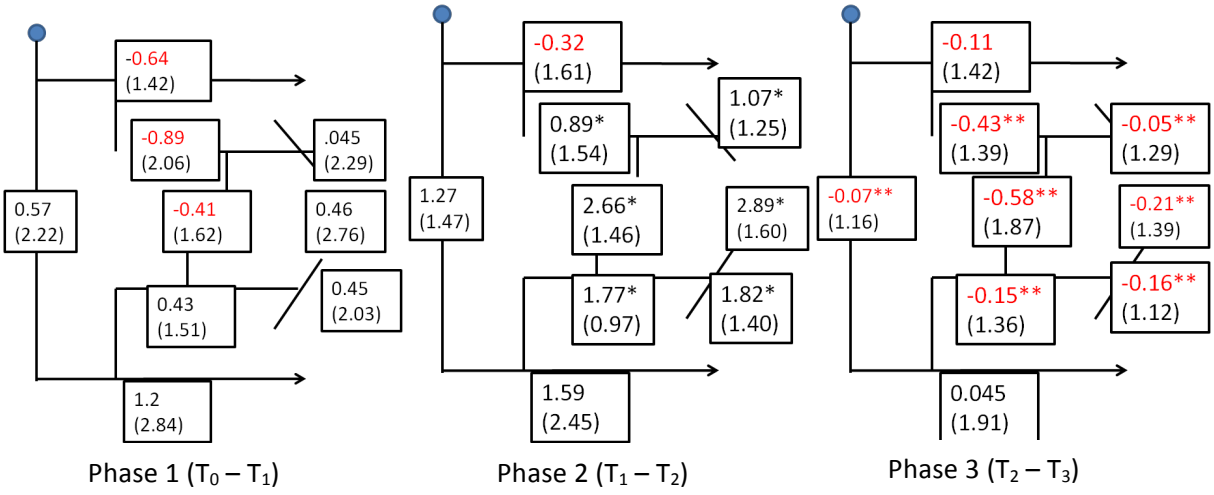
The mean changes observed during Treatment Phase 2, the Forsus™ treatment phase, are illustrated in Figure 18. As demonstrated, all measurements were positive and contributed toward correction of the Class II skeletal and dental relationships with the exception of slight forward movement of the maxilla and backward (upward in back) rotation of the occlusal plane.



Category	S – Gn	Occlusal Plane	U1	U6	L1	L6
Mean (SD)	**-0.5° (0.88)**	**0.74° (2.94)**	**-1.4° (4.61)**	**0.02° (4.40)**	**-1.95° (4.23)**	**-1.64° (3.88)**

Figure 19- Group 2 Mean Changes & (Standard Deviations) from Treatment Phase 3
*Improvements toward Class I or change toward reduction in Overjet illustrated as + (Black) and worsening of Class II or change toward increase in Overjet illustrated as – (Red).

Mean changes observed during Treatment Phase 3, the final finishing phase of comprehensive orthodontic treatment, are represented in Figure 19 and correspond to the effects observed following the removal of the Forsus™ appliance. As demonstrated, measured changes represent very minor relapse movements of the effects seen during the Forsus™ treatment phase, with the exception of a very slight and statistically insignificant forward movement of the Mandible.



	S – Gn	Occlusal Plane	U1	U6	L1	L6
Phase 1	**-0.73° (1.09)**	**+1.98° (2.36)**	**-0.36° (9.31)**	**-2.39 (4.28)**	**+1.14° (5.15)**	**-1.98° (4.39)**
Phase 2	**0.43° * (0.90)**	**-2.7° (3.55)**	**4.18° (3.92)**	**2.72° * (3.43)**	**6.4° * (4.11)**	**3.75° * (3.48)**
Phase 3	**-0.5° ** (0.88)**	**0.74° ** (2.94)**	**-1.4° ** (4.61)**	**0.02° (4.40)**	**-1.95° ** (4.23)**	**-1.64° ** (3.88)**

Figure 20- Comparison of Group 2 Treatment Phases
*denotes statistically significant difference between Phase 1 and 2 at p ≤ 0.05 level.
**denotes statistically significant difference between Phase 2 and 3 at p ≤ 0.05 level.

Figure 20 demonstrates, within Group 2, the mean changes observed during each successive treatment phase, which were compared via a paired Student t-Test with the level of significance established at $p \leq 0.05$. A comparison of changes observed during Treatment Phase 1 to those observed during Treatment Phase 2 revealed statistically significant differences in all measurements except Maxilla, Mandible, Apical Base change, and Maxillary incisor movement. A comparison of changes observed during Treatment Phase 2 to those observed during Treatment Phase 3 revealed significant differences in all measurements except Maxilla, Mandible, and Maxillary molar tip changes.

Treatment Phase 1: Initial to Pre-Forsus™ Changes

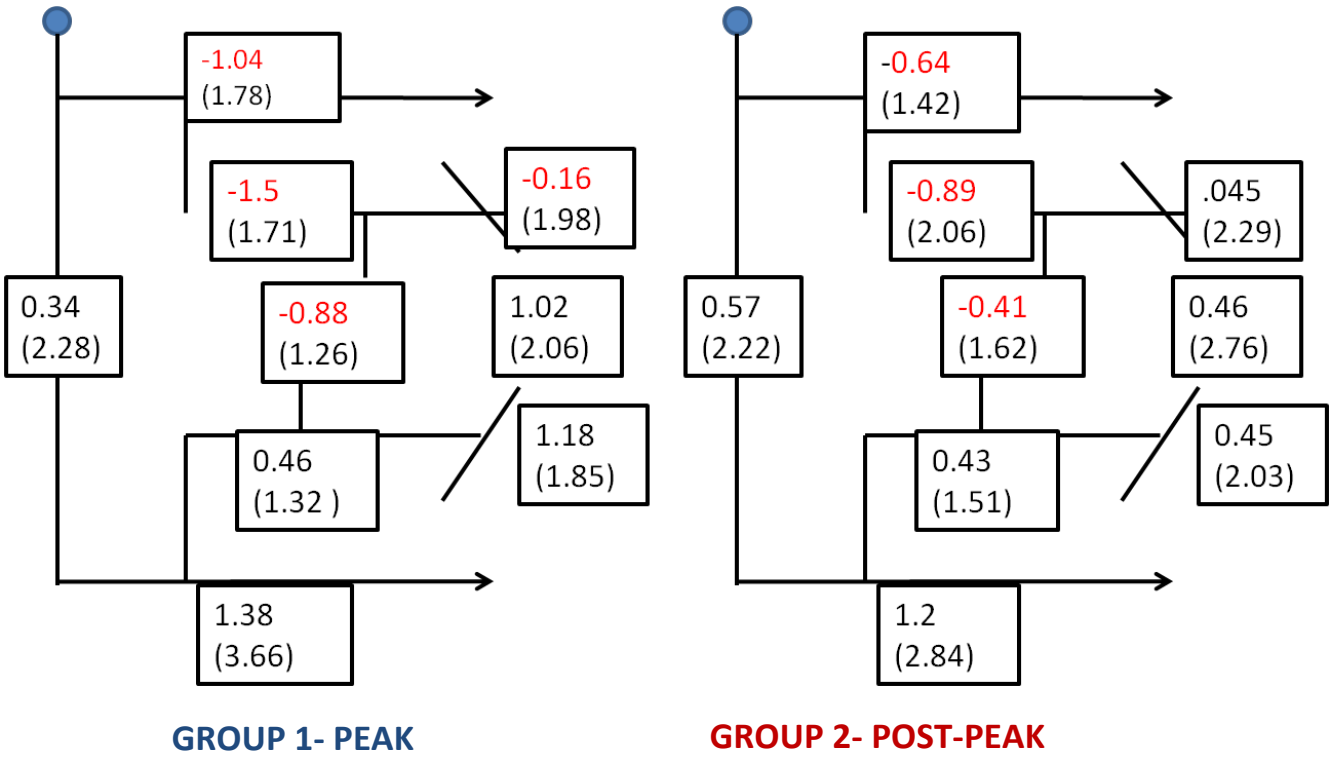


Figure 21- Mean Changes & (Standard Deviations) from Treatment Phase 1 (T_0 to T_1)
*Improvements toward Class I or change toward reduction in Overjet illustrated as + (Black) and worsening of Class II or change toward increase in Overjet illustrated as – (Red).

Table 5- Additional Skeletal and Dental Rotational Changes from Treatment Phase 1 ($T_0 – T_1$)

CATEGORY	GROUP 1- PEAK	GROUP 2- POST-PEAK
S – Gn	-0.92º (1.12)	-0.73º (1.09)
Occlusal Plane	+2.3º (3.42)	+1.98º (2.36)
U1	-2.88º (8.17)	-0.36º (9.31)
U6	-4.12º (4.18)	-2.39º (4.28)
L1	+2.94º (5.22)	+1.14º (5.15)
L6	-3.98º (3.58)	-1.98º (4.39)

*Improvements toward Class I or change toward reduction in Overjet illustrated as + (Black) and worsening of Class II or change toward increase in Overjet illustrated as – (Red).
**Standard deviations in parenthesis*

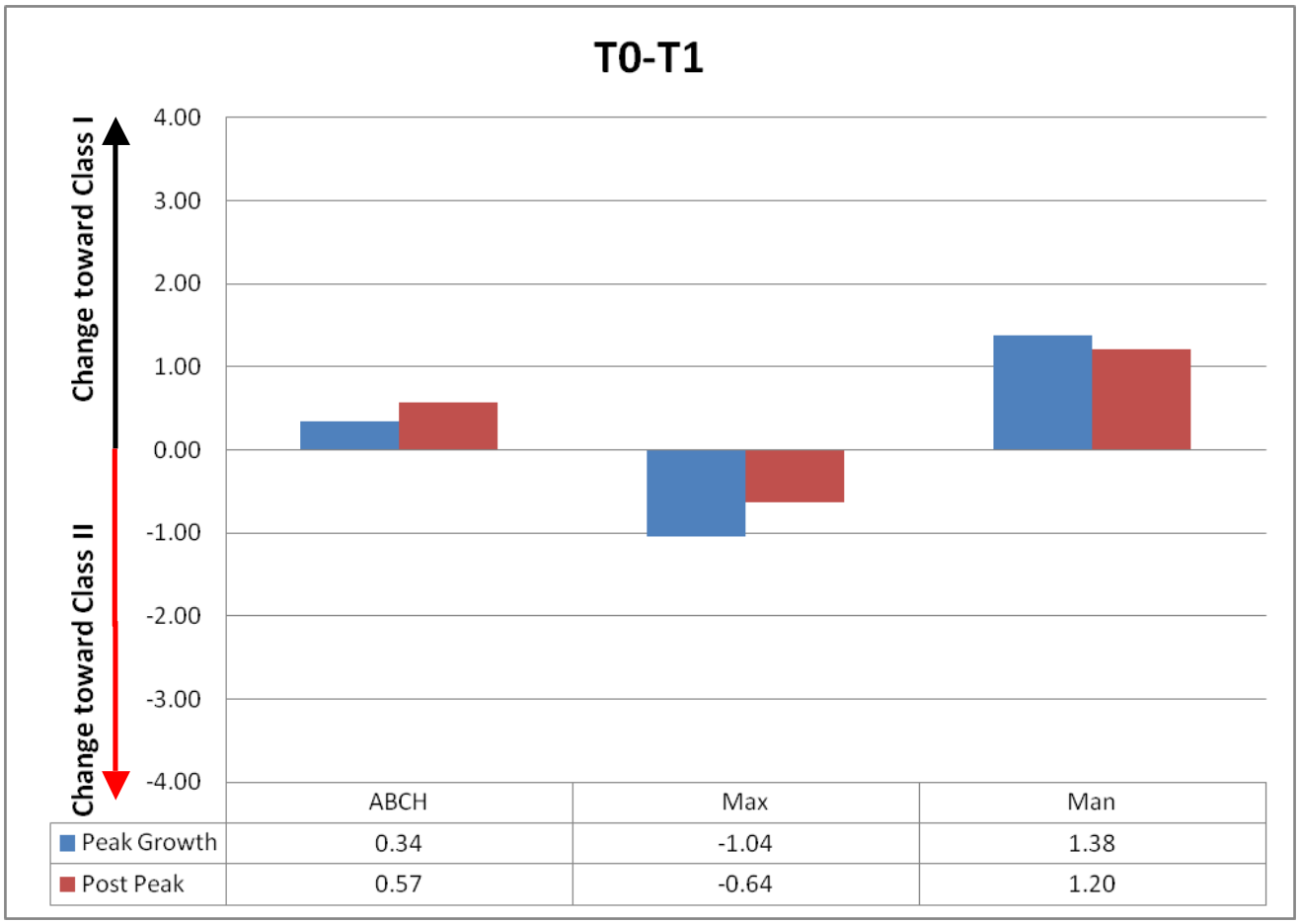


Figure 22: Comparison of Treatment Phase 1 Skeletal Changes

There were no significant differences between Groups 1 and 2 during Phase 1 of treatment (Figures 21 and 22; Table 5).

Treatment Phase 2: Pre- Forsus™ to Post- Forsus™ Changes:

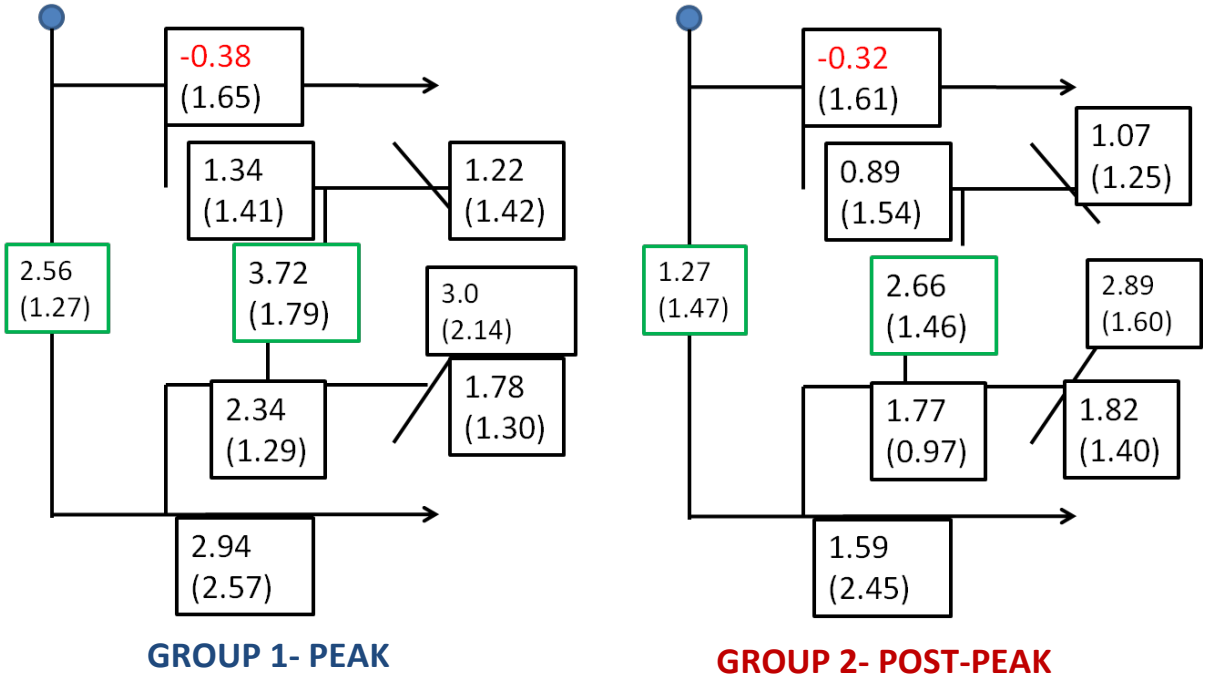


Figure 23- Mean Changes & (Standard Deviations) from Treatment Phase 2 (T_1 to T_2)
*Improvements toward Class I or change toward reduction in Overjet illustrated as + (Black) and worsening of Class II or change toward increase in Overjet illustrated as – (Red).
Green outline denotes significant difference.

Table 6- Additional Skeletal and Dental Rotational Changes from Treatment Phase 2 (T_1 – T_2)

CATEGORY	GROUP 1- PEAK	GROUP 2- POST-PEAK
S – Gn	0.4 °(1.19)	0.43 °(0.90)
Occlusal Plane	-2.64 °(3.16)	-2.7 °(3.55)
U1	4.44 °(4.84)	4.18 °(3.92)
U6	3.81 °(3.76)	2.72 °(3.43)
L1	6.18 °(3.07)	6.4 °(4.11)
L6	3.92 °(3.75)	3.75 °(3.48)

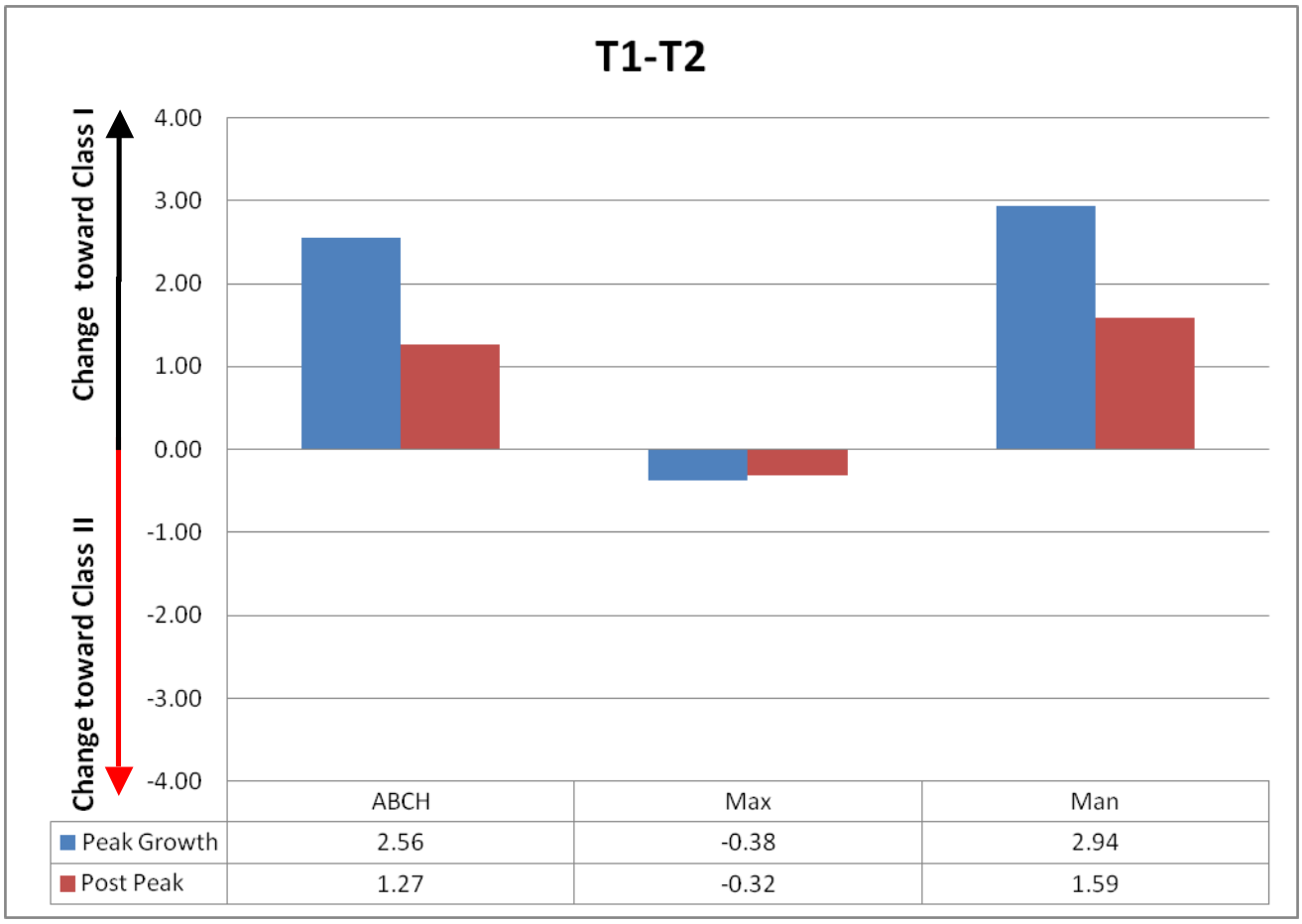


Figure 24: Treatment Phase 2 Skeletal Changes

Table 7: Mean rate (mm/month) of change from Treatment Phase 2 ($T_1 – T_2$)

	Max	Man	ABCH	Incisor	Molar
Group 1	**0.07**	**0.56**	**0.49**	**1.02**	**1.17**
Group 2	**0.06**	**0.32**	**0.26**	**0.81**	**0.77**

Groups were compared via an un-paired Student t-Test with the level of significance established at $p \leq 0.05$.

Patients in Group 1 showed a significantly higher mean apical base change (2.56mm) towards Class II correction than Group 2 (1.27mm) with $p \leq 0.01$. Although the increase in A-P position of the mandible in Group 1 was higher (2.94mm) than Group 2 (1.59mm) by nearly twice the amount of change, it was found to be insignificant statistically (Figures 23 and 24).

Molar change for Group 1 was significantly greater ($p \leq 0.03$) than Group 2 (3.72mm vs 2.66mm, respectively).

To evaluate the rate of change during the active Forsus™ therapy (Treatment Phase 2), comparisons were completed between the two groups. This revealed the mean treatment times while in the Forsus™ to be similar at 5.67 months for Group 1 and 5.49 months for Group 2. The difference in Apical Base Change rate was significantly higher ($p \leq 0.04$) in Group 1 (0.49mm/month) than in Group 2 (0.26mm/month).

Molar rate for Group 1 was found to be significantly greater ($p=0.003$) for Group 1 at 1.17mm/month while the rate for Group 2 was 0.77mm/month.

Treatment Phase 3: Post-Forsus to Final Changes

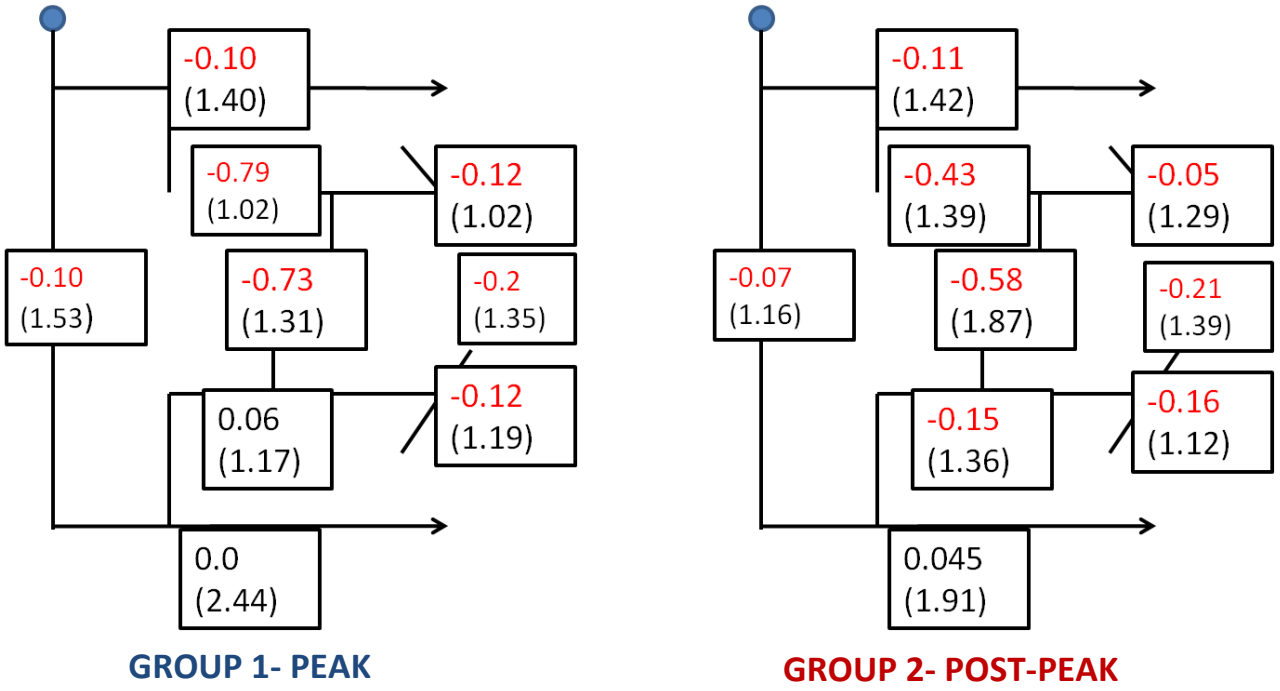


Figure 25: Mean Changes & (Standard Deviations) from Treatment Phase 3 (T_2 to T_3)
*Improvements toward Class I or change toward reduction in Overjet illustrated as + (Black) and worsening of Class II or change toward increase in Overjet illustrated as – (Red).

Table 8: Treatment Phase 3 Rotational Changes:

CATEGORY	GROUP 1- PEAK	GROUP 2- POST-PEAK
S – Gn	**-0.42° (1.26)**	**-0.5° (0.88)**
Occlusal Plane	**0.96° (2.86)**	**0.74° (2.94)**
U1	**-1.2° (3.53)**	**-1.4° (4.61)**
U6	**-0.58° (4.94)**	**0.02° (4.40)**
L1	**-1.8° (4.01)**	**-1.95° (4.23)**
L6	**-1.58° (3.58)**	**-1.64° (3.88)**

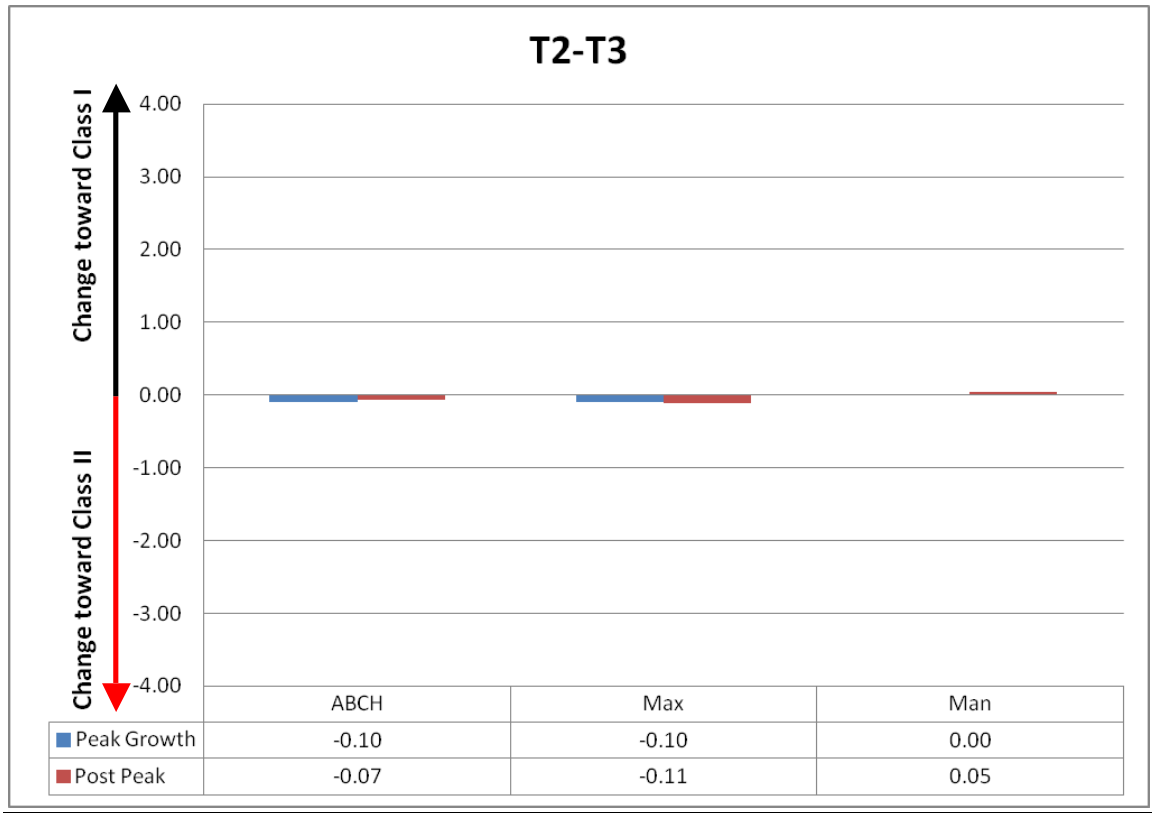


Figure 26: Treatment Phase 3 Skeletal Changes

There were no significant differences between Groups 1 and 2 during Phase 3 of treatment (Figures 25 and 26; Table 8).

DISCUSSION:

The results of this study provide valuable information regarding the effects of growth status during Class II correction with the Forsus™ appliance, as well as the individual skeletal and dental movements observed during the various phases that collectively comprise the total treatment. Utilizing cephalometric superimposition techniques based on implant studies, the methodology of this study offers the most exacting representation of the skeletal and dental changes observed during Forsus™ treatment. Superimposition of serial cephalometric radiographs on stable internal structures, rather than surface landmarks that can undergo substantial remodeling during treatment was utilized to optimize the accurate assessment of hard tissue change. Additionally, the two groups were extremely well matched according to the initial severity of the Class II, mandibular plane angle and the duration of the Forsus™ treatment phase. Therefore, differences observed during treatment were primarily a result of the particular growth status that the patients were experiencing upon the initiation of Forsus™ treatment. Previous studies and research have compared the Forsus™ with Class II elastics and/or with untreated Class II growth norms. The 2008 Jones study concluded that the Forsus™ was a good replacement for Class II elastics, having many of the same dentoalveolar effects. In the 2011 Franchi study, patients treated with the Forsus™ were compared to untreated Class II patients and concluded that the Forsus™ demonstrated growth modification effects by restraining skeletal growth of the maxilla. Although an increase in mandibular length was demonstrated in that study, the authors reported that the appliances' main mandibular effect was dentoalveolar in nature. The current study expands upon these previous reports that have demonstrated the

effectiveness of the Forsus™ appliance, by evaluating the efficiency of treatment demonstrated when treatment includes peak growth velocity. To demonstrate the dental and skeletal effects in both treatment groups, as well as the differences observed between the groups, it is helpful to discuss them chronologically as treatment progresses from Treatment Phase 1 (alignment/leveling and preparation for the Forsus™), to Treatment Phase 2 (active Forsus™ treatment), then ultimately to Treatment Phase 3 (treatment finishing/completion).

Treatment Phase 1:

Both groups demonstrated similar effects during alignment/leveling and preparation for the Forsus™ appliance. Minimal skeletal changes were observed and not directly related to alignment and leveling; both groups showed forward growth of the maxilla and mandible with minimal net changes overall. Slight backward rotation of the mandible was seen in both groups as the leveling was completed along with a mean forward rotation of the occlusal plane. The main dental effects were proclination of maxillary incisors, mesial movement and tipping of maxillary molars, distal uprighting of mandibular molars, and proclination of the mandibular incisors. Most of the changes noted demonstrate that many of the Class II attributes are initially worsened as a sequella of the straight-wire technique. Therefore, although teeth are aligned, up-righted, and leveled, it comes at the price of needing a greater amount of skeletal or dental AP effect to ultimately correct the Class II relationship.

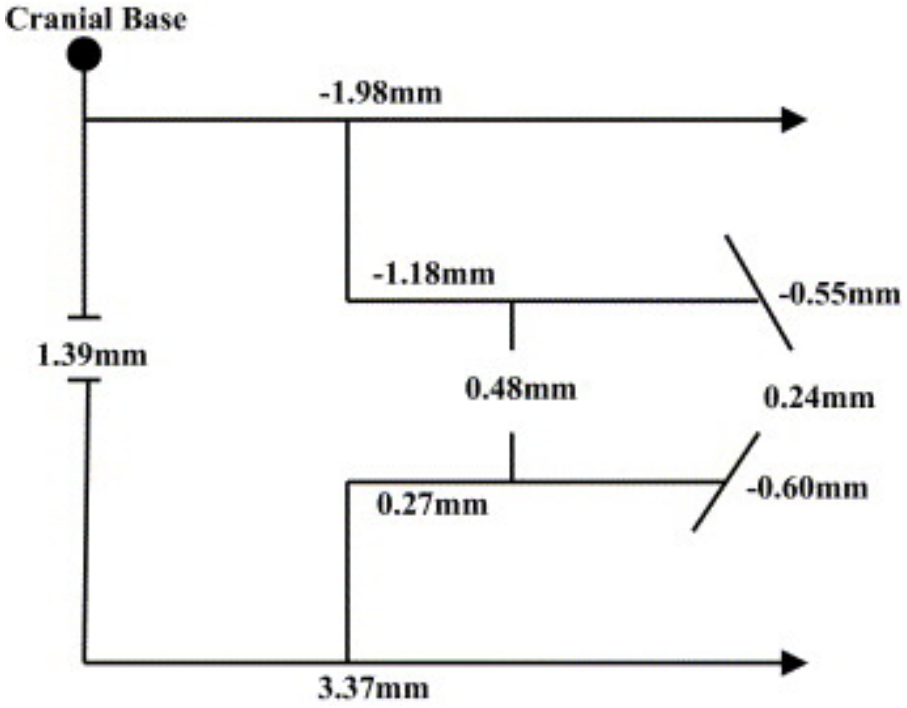


Figure 27: Mean Untreated Class II Changes (Jena 2006)

Treatment Phase 2:

The overall effectiveness and efficiency of Class II treatment was influenced by the growth status the patient was experiencing when Forsus™ treatment was initiated. The amount and rate of apical base change was significantly greater in Group 1, demonstrating the synergistic effect of the Maxilla and Mandible (which was nearly twice the change as in Phase 1) changes of patients in peak growth even though their individual contributions were found to be statistically insignificant. Group 2 showed less maxilla and mandible contributions due to patients being treated past their peak growth with less apical base change occurring.

The dental contribution to molar correction was also significantly greater in Group 1 with amount and rate of change. Overjet was reduced in both groups due to significant uprighting and retraction of the maxillary incisors, along with mandibular incisor advancement and proclination. These changes with incisor inclination are the typical incisor response to functional appliances; however, in Group 1 the mandibular incisors did not show significant movement. This was due to the greater skeletal contribution of the mandible carrying the lower incisors anterior (translational advancement). Overall, more mesial movement of the mandibular dentition than distal movement of the maxillary dentition was observed in both groups.

When taking into account the Treatment Phase 2 effect on skeletal and dental changes, the mean amount of molar correction during peak growth was 6.3mm; 40% of which was skeletal contribution. While 3.9mm of correction was obtained in the post peak growth patients; 25% of which was from skeletal contribution.

The increased molar change in Group 1 was partly due to the initial dental Class II relationship being more severe. Most patients in Group 1 began with a full step Class II molar relationship. So while the neither group showed a more severe Class II skeletal relationship, Group 2 on average had a smaller amount of molar correction required to obtain a Class I relationship.

Rotational effects from the Forsus™ on both groups showed a forward rotation of the mandible and a backward rotation of occlusal plane. These effects are due to the Forsus™ holding the position or slightly intruding the maxillary molars.

The forward rotation of the mandible, although slight also contributed toward Class II correction.

In comparing both groups to the untreated Class II patients used in the 2006 Jena study, both had similar amounts and rates of anterior movement of the maxilla, that were less than the mean untreated amount of 1.98mm of anterior maxillary growth used in the 2006 Jena Twin Block study (Figure 27).

This restrictive force on the maxilla is the typical headgear effect resulting from use of functional appliances. This same effect was also observed during treatment with the Twin Block and Bionator in the 2006 Jena study, the Forsus ^{TM} in the 2011 Franchi study, and with the Mandibular Anterior Repositioning Appliance (MARA) in the 2012 Huanca Ghislanzoni study. Patients in Group 1 of this study actually showed net average treatment changes similar to that of the Bionator group in the Jones study and greater changes than the Forsus™ group from the Jones study.

Small samples of pre-peak growth patients (CS1-CS2) were also analyzed and the net mean changes towards Class II correction were actually greater than those found for Group 1 (peak growth). However additional studies, with larger sample sizes, are needed to anlayze this further.

Treatment Phase 3:

Upon completion of Treatment Phase 3, both groups demonstrated similar effects during orthodontic finishing and completion of comprehensive orthodontic treatment. Most changes observed revealed minimal relapse. The molar relationship showed a relatively high relapse with this mostly due to mesial movement of the maxillary molars and distal tip of the mandibular molars. Rotational relapse also occurred with backward rotation of the mandible and forward rotation of occlusal plane. This relapse must be

considered when monitoring A-P correction with the Forsus™ and indicates overcorrection by 0.75-1mm at the molars in most cases.

With Class II correction, the occlusion represents the “bottom line” (Johnston 1996). It is the site where maxilla and mandible changes come together skeletally and dentally and one is hopeful that the net result is enough to obtain a Class I relationship. When the patient is in your chair, molar relation and overjet are still the primary indicators for the progress of A-P correction.

While the skeletal and molar results were significantly higher with the group 1, the Forsus™ was still able to provide Class II correction in Group 2 patients who were past peak growth.

CONCLUSION

Within the parameters of this study, the following conclusions can be drawn:

Patients treated with the Forsus™ appliance during peak growth demonstrate a greater mean skeletal change towards Class II correction at a higher rate than patients treated during the post-peak growth phase. Patients treated with a Forsus™ appliance during peak growth also showed greater molar change towards Class II correction and at a higher rate.

Therefore, the primary and secondary null hypotheses in this study were rejected, as Forsus™ treatment during the stage of increased growth velocity was more effective and more efficient in correcting Class II skeletal and dental relationships than treatment past the peak growth stage.

Appendix A: Raw Data

Skeletal Changes:

Patient ID#	Growth status	Timepoint	S-Gn (degree	ABCH(mm)	Max (mm)	Man(mm)	%MolarSkeletal	%SkeletalIncisor
1	Peak growth	T0-T1	0	-1	1	-2	0.50	2
2	Peak growth	T0-T1	-0.5	-1	-1.5	0.5	0.22	0.67
3	post peak	T0-T1	-1.5	0	-1	1	0.00	0
4	Peak growth	T0-T1	-5	4	-2.5	6.5	0.89	1.6
5	post peak	T0-T1	0	1	1	0	0.40	0.25
7	Peak growth	T0-T1	-1.5	6.5	-4.5	11	0.81	0.764705882
8	pre-peak	T0-T1	-1	1	-2.5	3.5	-0.50	0.166666667
9	post peak	T0-T1	-1.5	-4	-1	-3	1.60	0.470588235
10	Peak growth	T0-T1	-1	0	1	-1	0.00	0
12	Peak growth	T0-T1	0	1	-1	2	1.00	-0.4
13	pre-peak	T0-T1	-1	1	1	0	1.00	0.181818182
14	post peak	T0-T1	-1.5	0.5	-1.5	2	-0.50	0.142857143
15	Peak growth	T0-T1	-0.5	-2.5	1	-3.5	0.71	0.714285714
16	pre-peak	T0-T1	-3	1	1	0	2.00	0.333333333
17	Peak growth	T0-T1	1	2.5	-1	3.5	-5.00	0.357142857
18	post peak	T0-T1	-0.5	1	1	0	0.00	1
19	post peak	T0-T1	-0.5	-1	-1	0	0.00	0.4
20	post peak	T0-T1	0	5.5	-2	7.5	1.57	1.1
21	Peak growth	T0-T1	-1	4	-6	10	1.33	0.666666667
23	Peak growth	T0-T1	-1	0	1	-1	0.00	0
24	Peak growth	T0-T1	-2	-2	-2	0	0.50	2
25	post peak	T0-T1	-3	-1	1	-2	0.40	1
27	post peak	T0-T1	0.5	0.5	0	0.5	-0.50	-1
28	post peak	T0-T1	-0.5	1	-3.5	4.5	0.00	-0.333333333
29	post peak	T0-T1	-1.5	-1	-2	1	-0.67	-0.181818182
30	post peak	T0-T1	3	6.5	-2	8.5	1.63	0.8125
31	post peak	T0-T1	-1	1.5	1	0.5	0.00	0.5
32	Peak growth	T0-T1	0	3	-2	5	1.20	0.75
33	Peak growth	T0-T1	-0.5	-3	-1	-2	1.00	-6
34	post peak	T0-T1	-1	0	-3	3	0.00	0
35	post peak	T0-T1	-1	-1.5	0	-1.5	1.50	-3
36	Peak growth	T0-T1	-1	-2	-1	-1	0.67	-0.666666667
37	post peak	T0-T1	-1	0	-2	2	0.00	0
38	Peak growth	T0-T1	-1.5	-1	-1	0	0.33	1
40	pre-peak	T0-T1	-0.5	0	-1	1	0.00	0
41	Peak growth	T0-T1	0.5	0	0	0	0.00	0
42	post peak	T0-T1	-1	2	0.5	1.5	-4.00	0.333333333
43	pre-peak	T0-T1	0.5	0	-1	1	0.00	0
44	pre-peak	T0-T1	1	0.5	0	0.5	-1.00	1
45	post peak	T0-T1	-0.5	0	0	0	0.00	0
46	pre-peak	T0-T1	1	-1	-1.5	0.5	-0.22	-0.1
47	post peak	T0-T1	-0.5	2	-1.5	3.5	0.67	0.363636364
48	post peak	T0-T1	-1	0	0.5	-0.5	0.00	0
49	Peak growth	T0-T1	-1.5	0.5	0.5	0	-0.50	0.125
50	Peak growth	T0-T1	-1	2	-2	4	1.00	1
51	Peak growth	T0-T1	-2	-1	2	-3	0.67	2
52	Peak growth	T0-T1	-1	0	0	0	0.00	0
53	Peak growth	T0-T1	-1	-2	-1	-1	2.00	0
54	Peak growth	T0-T1	0	0	0	0	0.00	0
55	Peak growth	T0-T1	-0.5	0	-1.5	1.5	0.00	0
56	post peak	T0-T1	-1	-1.5	0	-1.5	1.00	-3
57	post peak	T0-T1	-1	1	1.5	-0.5	2.00	-0.4
58	Peak growth	T0-T1	-1	-0.5	-2.5	2	0.00	-0.25
59	Peak growth	T0-T1	-1	1	-2	3	-1.00	0.25

Patient ID#	Growth status	Timepoint	S-Gn (degrees)	ABCH(mm)	Max (mm)	Man(mm)	%MolarSkeletal	%SkeletalIncisor
1	Peak growth	T1-T-2	-1	4	2	2	0.89	0.666666667
2	Peak growth	T1-T-2	2	2	-3	5	0.40	0.5
3	post peak	T1-T-2	2	0	2	-2	0.00	0
4	Peak growth	T1-T-2	2	4.5	-1.5	6	0.69	0.692307692
5	post peak	T1-T-2	1	2.5	-1.5	4	0.63	0.416666667
7	Peak growth	T1-T-2	1	1.5	3	-1.5	0.43	0.428571429
8	pre-peak	T1-T-2	2	5	-1.5	6.5	0.50	0.454545455
9	post peak	T1-T-2	0	3	0	3	0.43	0.375
10	Peak growth	T1-T-2	-0.5	4	-1	5	0.47	0.363636364
12	Peak growth	T1-T-2	-1	1.5	-1	2.5	0.23	0.2
13	pre-peak	T1-T-2	1	4.5	-2	6.5	0.75	0.818181818
14	post peak	T1-T-2	0.5	1	0	1	0.22	0.2
15	Peak growth	T1-T-2	-0.5	2	-1	3	0.31	0.285714286
16	pre-peak	T1-T-2	1.5	0	1	-1	0.00	0
17	Peak growth	T1-T-2	0	0.5	-0.5	1	0.11	0.111111111
18	post peak	T1-T-2	0	2	-1	3	0.33	0.307692308
19	post peak	T1-T-2	-0.5	1.5	-1	2.5	0.25	0.25
20	post peak	T1-T-2	0	0	1.5	-1.5	0.00	0
21	Peak growth	T1-T-2	0	2.5	-1	3.5	0.45	0.714285714
23	Peak growth	T1-T-2	2	3	1	2	0.50	0.666666667
24	Peak growth	T1-T-2	1	6	2.5	3.5	0.75	1.5
25	post peak	T1-T-2	2.5	3.5	-3	6.5	0.78	0.583333333
27	post peak	T1-T-2	0	-0.5	-1	0.5	-0.20	-0.1
28	post peak	T1-T-2	1	2	2	0	0.40	0.571428571
29	post peak	T1-T-2	0	2.5	-2	4.5	0.56	0.5
30	post peak	T1-T-2	0	-1	-1	0	-0.67	0.666666667
31	post peak	T1-T-2	1	1.5	-3	4.5	0.27	0.6
32	Peak growth	T1-T-2	0.5	2	-1	3	0.40	0.444444444
33	Peak growth	T1-T-2	2	5.5	-3	8.5	0.50	0.55
34	post peak	T1-T-2	-1	-2	1	-3	-1.33	0
35	post peak	T1-T-2	1	2	0.5	1.5	0.33	0.333333333
36	Peak growth	T1-T-2	-0.5	3	-1	4	0.33	0.285714286
37	post peak	T1-T-2	0	2	2.5	-0.5	0.67	0.5
38	Peak growth	T1-T-2	1	2.5	-0.5	3	0.45	0.555555556
40	pre-peak	T1-T-2	-1	1	1	0	0.33	0.285714286
41	Peak growth	T1-T-2	1.5	4.5	-1.5	6	0.50	0.6
42	post peak	T1-T-2	1	0	0	0	0.00	0
43	pre-peak	T1-T-2	1	4.5	0.5	4	1.13	1
44	pre-peak	T1-T-2	-1	0.5	0.5	0	0.08	0.111111111
45	post peak	T1-T-2	-1	2.5	0	2.5	1.25	0.454545455
46	pre-peak	T1-T-2	0.5	2.5	0	2.5	1.25	1
47	post peak	T1-T-2	-0.5	0	-1	1	0.00	0
48	post peak	T1-T-2	1.5	1	-2.5	3.5	0.22	0.333333333
49	Peak growth	T1-T-2	1	2	-0.5	2.5	0.22	0.5
50	Peak growth	T1-T-2	0	2.5	0.5	2	0.42	0.714285714
51	Peak growth	T1-T-2	2	2	1	1	0.44	0.5
52	Peak growth	T1-T-2	-2	0	2	-2	0.00	0
53	Peak growth	T1-T-2	0	3	-2.5	5.5	0.60	0.545454545
54	Peak growth	T1-T-2	0.5	2	1	1	0.44	0.571428571
55	Peak growth	T1-T-2	0	4.5	-2.5	7	0.69	0.692307692
56	post peak	T1-T-2	1	1	1.5	-0.5	0.25	0.4
57	post peak	T1-T-2	0	3.5	-1	4.5	0.64	0.7
58	Peak growth	T1-T-2	-2	-1	-1	0	-0.20	-0.2
59	Peak growth	T1-T-2	1	0	0	0	0.00	0

Patient ID#	Growth status	Timepoint	S-Gn (degrees)	ABCH(mm)	Max (mm)	Man(mm)	%MolarSkeletal	%SkeletalIncisor
1	Peak growth	T2-T3	-0.5	-1	-3	2	-2.00	1
2	Peak growth	T2-T3	-1.5	0	-1	1	0.00	0
3	post peak	T2-T3	-1	-1.5	0	-1.5	0.60	1.5
4	Peak growth	T2-T3	-1	-3	1.5	-4.5	1.00	1.2
5	post peak	T2-T3	-1	-2.5	-2	-0.5	1.67	-5
7	Peak growth	T2-T3	-2	-2	1.5	-3.5	0.40	0.8
8	pre-peak	T2-T3	-2	-3	1	-4	0.67	0.545454545
9	post peak	T2-T3	-1	-0.5	2	-2.5	-1.00	0
10	Peak growth	T2-T3	1	2	1	1	1.33	-2
12	Peak growth	T2-T3	0	2	0	2	2.00	4
13	pre-peak	T2-T3	0	1	-1	2	0.00	0
14	post peak	T2-T3	0.5	-1	1	-2	0.50	0.5
15	Peak growth	T2-T3	-0.5	-2	1.5	-3.5	0.80	1.333333333
16	pre-peak	T2-T3	-1.5	1	0	1	-0.50	0
17	Peak growth	T2-T3	-2	-2	2	-4	0.57	2
18	post peak	T2-T3	-2	-1	1	-2	0.25	1
19	post peak	T2-T3	-2	0.5	-2	2.5	0.33	1
20	post peak	T2-T3	-1	0	0.5	-0.5	0.00	0
21	Peak growth	T2-T3	1	0.5	-1	1.5	-1.00	-1
23	Peak growth	T2-T3	-1	0	-0.5	0.5	0.00	0
24	Peak growth	T2-T3	-0.5	0	-2	2	0.00	0
25	post peak	T2-T3	-1	0	-1	1	0.00	0
27	post peak	T2-T3	0	-1	1	-2	1.00	1
28	post peak	T2-T3	-0.5	0	-2	2	0.00	0
29	post peak	T2-T3	0	1	1.5	-0.5	-0.29	0
30	post peak	T2-T3	1	2	-2	4	2.00	1
31	post peak	T2-T3	-1.5	-2	1.5	-3.5	2.00	4
32	Peak growth	T2-T3	-1	-2	0	-2	0.67	1.333333333
33	Peak growth	T2-T3	-1	-1	-1.5	0.5	0.50	2
34	post peak	T2-T3	-1	0	-3.5	3.5	0.00	0
35	post peak	T2-T3	-0.5	0	0.5	-0.5	0.00	0
36	Peak growth	T2-T3	-1	-1.5	3	-4.5	0.60	1
37	post peak	T2-T3	-1	1	0	1	-1.00	0
38	Peak growth	T2-T3	-1	1.5	-1	2.5	1.00	1
40	pre-peak	T2-T3	1	1	0	1	-1.00	1
41	Peak growth	T2-T3	-1	1.5	0.5	1	-3.00	3
42	post peak	T2-T3	1	2	1	1	-2.00	0
43	pre-peak	T2-T3	0.5	1	-1.5	2.5	0.50	0.25
44	pre-peak	T2-T3	0.5	2	0	2	0.00	1.333333333
45	post peak	T2-T3	1	0	-0.5	0.5	0.00	0
46	pre-peak	T2-T3	-1	-2	-1	-1	1.00	1.333333333
47	post peak	T2-T3	0	0	0	0	0.00	0
48	post peak	T2-T3	-1	1	0	1	0.00	2
49	Peak growth	T2-T3	-1	-1	-1	0	-1.00	-2
50	Peak growth	T2-T3	1	0	0	0	0.00	0
51	Peak growth	T2-T3	-0.5	1.5	0	1.5	0.00	3
52	Peak growth	T2-T3	3	1.5	-2	3.5	-0.75	-1.5
53	Peak growth	T2-T3	-2	-1	0	-1	0.00	-1
54	Peak growth	T2-T3	-2	-1	1	-2	1.00	0
55	Peak growth	T2-T3	1	1.5	-1.5	3	1.00	0.375
56	post peak	T2-T3	0	1	0.5	0.5	-0.50	-1
57	post peak	T2-T3	0	-0.5	0	-0.5	-2.00	0.333333333
58	Peak growth	T2-T3	1	2	0	2	-4.00	2
59	Peak growth	T2-T3	1	1	0	1	0.00	-0.666666667

Dental A-P Changes:

Patient ID#	Growth status	Timepoint	U6(mm)	L6(mm)	Molar(mm)	U1(mm)	L1(mm)	OJ(mm)	Total Molar	Total Incisor
1	Peak growth	T0-T1	-1	0	-1	-2	2.5	0.5	0	1.5
2	Peak growth	T0-T1	-3.5	0	-3.5	-1.5	1	-0.5	-1.5	1.5
3	post peak	T0-T1	-1.5	2	0.5	-2	3	1	3.5	4
4	Peak growth	T0-T1	-2	2.5	0.5	1.5	-3	-1.5	4.5	2.5
5	post peak	T0-T1	0	1.5	1.5	1	2	3	6.5	8
7	Peak growth	T0-T1	-0.5	2	1.5	0	2	2	8.5	9
8	pre-peak	T0-T1	-1	-2	-3	0	5	5	5	13
9	post peak	T0-T1	3.5	-2	1.5	-2.5	-2	-4.5	10.5	4.5
10	Peak growth	T0-T1	-5	-1	-1.5	0	-1	-1	8.5	9
12	Peak growth	T0-T1	-2.5	1.5	-1	-4	0.5	-3.5	11	8.5
13	pre-peak	T0-T1	1	-1	0	2.5	2	4.5	13	17.5
14	post peak	T0-T1	-1.5	0	-1.5	2	1	3	12.5	17
15	Peak growth	T0-T1	-1	0	-1	-2	1	-1	14	14
16	pre-peak	T0-T1	-6.5	3	-0.5	-1	3	2	15.5	18
17	Peak growth	T0-T1	-3	0	-3	2.5	2	4.5	14	21.5
18	post peak	T0-T1	-1	0	-1	2	-2	0	17	18
19	post peak	T0-T1	1	0	1	1	-2.5	-1.5	20	17.5
20	post peak	T0-T1	-4	2	-2	1	-1.5	-0.5	18	19.5
21	Peak growth	T0-T1	-2	1	-1	0	2	2	20	23
23	Peak growth	T0-T1	0.5	0	0.5	1	-1	0	23.5	23
24	Peak growth	T0-T1	-5	3	-2	2	-1	1	22	25
25	post peak	T0-T1	-0.5	-1	-1.5	1	-1	0	23.5	25
27	post peak	T0-T1	-2.5	1	-1.5	2	-3	-1	25.5	26
28	post peak	T0-T1	-5	4	-1	-1	-3	-4	27	24
29	post peak	T0-T1	1.5	1	2.5	5.5	1	6.5	31.5	35.5
30	post peak	T0-T1	-4.5	2	-2.5	0	1.5	1.5	27.5	31.5
31	post peak	T0-T1	-1	-0.5	-1.5	-1.5	3	1.5	29.5	32.5
32	Peak growth	T0-T1	-1	0.5	-0.5	1	0	1	31.5	33
33	Peak growth	T0-T1	0	0	0	-1.5	5	3.5	33	36.5
34	post peak	T0-T1	0	-1	-1	-1	2.5	1.5	33	35.5
35	post peak	T0-T1	1	-1.5	0.5	1	1	2	35.5	37
36	Peak growth	T0-T1	-3	2	-1	1	4	5	35	41
37	post peak	T0-T1	0	2	2	-2	1	-1	39	36
38	Peak growth	T0-T1	-3	1	-2	-1	1	0	36	38
40	pre-peak	T0-T1	1	0	1	0	6	6	41	46
41	Peak growth	T0-T1	-0.5	-2	-2.5	1.5	1.5	3	38.5	44
42	post peak	T0-T1	-3	0.5	-2.5	3	1	4	39.5	46
43	pre-peak	T0-T1	2	0.5	2.5	-1	1.5	0.5	45.5	43.5
44	pre-peak	T0-T1	-2	1	-1	-1.5	1.5	0	43	44
45	post peak	T0-T1	0.5	0	0.5	-3.5	1	-2.5	45.5	42.5
46	pre-peak	T0-T1	3	2.5	5.5	6	5	11	51.5	57
47	post peak	T0-T1	-1	2	1	0.5	4	3.5	48	50.5
48	post peak	T0-T1	-2	-1.5	-3.5	-1.5	0.5	-1	44.5	47
49	Peak growth	T0-T1	-0.5	-1	-1.5	2	1.5	3.5	47.5	52.5
50	Peak growth	T0-T1	-1	1	0	-3	3	0	50	50
51	Peak growth	T0-T1	-1.5	1	-0.5	0.5	0	0.5	50.5	51.5
52	Peak growth	T0-T1	-2	2	0	-4	4.5	0.5	52	52.5
53	Peak growth	T0-T1	3	-2	1	3	-1	2	54	55
54	Peak growth	T0-T1	0	0	0	-1.5	1.5	0	54	54
55	Peak growth	T0-T1	-1	-1	-2	-2	0.5	-1.5	53	53.5
56	post peak	T0-T1	1	-1	0	0.5	1.5	2	56	58
57	post peak	T0-T1	-0.5	0	-0.5	-4.5	1	-3.5	56.5	53.5
58	Peak growth	T0-T1	-1	1.5	0.5	1.5	1	2.5	58.5	60.5
59	Peak growth	T0-T1	-1.5	-0.5	-2	1	2	3	57	62

Patient ID#	Growth status	Timepoint	U6(mm)	L6(mm)	Molar(mm)	U1(mm)	L1(mm)	OJ(mm)	Total Molar	Total Incisor
1	Peak growth	T1-T-2	-2	1.5	0.5	1	1	2	1.5	3
2	Peak growth	T1-T-2	1	2	3	1	1	2	5	4
3	post peak	T1-T-2	-1	2.5	1.5	1	0	1	4.5	4
4	Peak growth	T1-T-2	2	0	2	0	2	2	6	6
5	post peak	T1-T-2	1.5	0	1.5	2	1.5	3.5	6.5	8.5
7	Peak growth	T1-T-2	0	2	2	1	1	2	9	9
8	pre-peak	T1-T-2	2.5	2.5	5	2.5	3.5	6	13	14
9	post peak	T1-T-2	0.5	3.5	4	1	4	5	13	14
10	Peak growth	T1-T-2	1.5	3	4.5	3.5	3.5	7	14.5	17
12	Peak growth	T1-T-2	3	2	5	4	2	6	17	18
13	pre-peak	T1-T-2	0	1.5	1.5	0	1	1	14.5	14
14	post peak	T1-T-2	-0.5	4	3.5	0	4	4	17.5	18
15	Peak growth	T1-T-2	1	3.5	4.5	3	2	5	19.5	20
16	pre-peak	T1-T-2	4	2.5	6.5	3	3	6	22.5	22
17	Peak growth	T1-T-2	1.5	2.5	4	0	4	4	21	21
18	post peak	T1-T-2	2	2	4	3	1.5	4.5	22	22.5
19	post peak	T1-T-2	3	1.5	4.5	1.5	3	4.5	23.5	23.5
20	post peak	T1-T-2	-2	2	0	2.5	1	3.5	20	23.5
21	Peak growth	T1-T-2	1	2	3	2	-1	1	24	22
23	Peak growth	T1-T-2	1.5	1.5	3	-0.5	2	1.5	26	24.5
24	Peak growth	T1-T-2	1	1	2	-1	-1	-2	26	22
25	post peak	T1-T-2	-1	2	1	2	0.5	2.5	26	27.5
27	post peak	T1-T-2	2	1	3	2.5	3	5.5	30	32.5
28	post peak	T1-T-2	3	0	3	1	0.5	1.5	31	29.5
29	post peak	T1-T-2	1	1	2	1.5	1	2.5	31	31.5
30	post peak	T1-T-2	1.5	1	2.5	-1	0.5	-0.5	32.5	29.5
31	post peak	T1-T-2	2	2	4	0	1	1	35	32
32	Peak growth	T1-T-2	1	2	3	1.5	1	2.5	35	34.5
33	Peak growth	T1-T-2	2.5	3	5.5	2.5	2	4.5	38.5	37.5
34	post peak	T1-T-2	1	2.5	3.5	1	1	2	37.5	36
35	post peak	T1-T-2	2	2	4	2	2	4	39	39
36	Peak growth	T1-T-2	1.5	4.5	6	4	3.5	7.5	42	43.5
37	post peak	T1-T-2	-1	2	1	-2	4	2	38	39
38	Peak growth	T1-T-2	2	1	3	1	1	2	41	40
40	pre-peak	T1-T-2	-2	4	2	1.5	1	2.5	42	42.5
41	Peak growth	T1-T-2	2	2.5	4.5	0.5	2.5	3	45.5	44
42	post peak	T1-T-2	2.5	2.5	5	1	4.5	5.5	47	47.5
43	pre-peak	T1-T-2	1	-1.5	-0.5	-1	1	0	42.5	43
44	pre-peak	T1-T-2	3	3	6	1.5	2.5	4	50	48
45	post peak	T1-T-2	-2	1.5	-0.5	2.5	0.5	3	44.5	48
46	pre-peak	T1-T-2	0	-0.5	-0.5	-1	1	0	45.5	46
47	post peak	T1-T-2	2	0.5	2.5	1	2.5	3.5	49.5	50.5
48	post peak	T1-T-2	2	1.5	3.5	0	2	2	51.5	50
49	Peak growth	T1-T-2	2.5	4.5	7	1	1	2	56	51
50	Peak growth	T1-T-2	-1	4.5	3.5	1	0	1	53.5	51
51	Peak growth	T1-T-2	2.5	0	2.5	-1	3	2	53.5	53
52	Peak growth	T1-T-2	5	3	8	0	3.5	3.5	60	55.5
53	Peak growth	T1-T-2	-1.5	3.5	2	0.5	2	2.5	55	55.5
54	Peak growth	T1-T-2	1	1.5	2.5	0	1.5	1.5	56.5	55.5
55	Peak growth	T1-T-2	1	1	2	1	1	2	57	57
56	post peak	T1-T-2	1	2	3	1.5	0	1.5	59	57.5
57	post peak	T1-T-2	0	2	2	-0.5	2	1.5	59	58.5
58	Peak growth	T1-T-2	2	4	6	2.5	3.5	6	64	64
59	Peak growth	T1-T-2	1.5	2.5	4	2	2.5	4.5	63	63.5

Patient ID#	Growth status	Timepoint	U6(mm)	L6(mm)	Molar(mm)	U1(mm)	L1(mm)	OJ(mm)	Total Molar	Total Incisor
1	Peak growth	T2-T3	0.5	1	1.5	-1	1	0	2.5	1
2	Peak growth	T2-T3	0.25	1	1.25	0.5	0	0.5	3.25	2.5
3	post peak	T2-T3	1	-2	-1	1.5	-1	0.5	2	3.5
4	Peak growth	T2-T3	0	0	0	1.5	-1	0.5	4	4.5
5	post peak	T2-T3	1	0	1	2	1	3	6	8
7	Peak growth	T2-T3	-1	-2	-3	0	-0.5	-0.5	4	6.5
8	pre-peak	T2-T3	-1.5	-3	-1.5	0	-2.5	-2.5	6.5	5.5
9	post peak	T2-T3	2	-1	1	1	-0.5	0.5	10	9.5
10	Peak growth	T2-T3	-0.5	0	-0.5	-1	-2	-3	9.5	7
12	Peak growth	T2-T3	0.5	-1.5	-1	-1.5	0	-1.5	11	10.5
13	pre-peak	T2-T3	-1.5	0.5	-1	1	-2	-1	12	12
14	post peak	T2-T3	0	-1	-1	1	-2	-1	13	13
15	Peak growth	T2-T3	1.5	-2	-0.5	0	0.5	0.5	14.5	15.5
16	pre-peak	T2-T3	-2	-1	-3	0	-1	-1	13	15
17	Peak growth	T2-T3	-0.5	-1	-1.5	2	-1	1	15.5	18
18	post peak	T2-T3	-1	-2	-3	-1	1	0	15	18
19	post peak	T2-T3	-1	2	1	-1	1	0	20	19
20	post peak	T2-T3	-1	1	0	1	-1	0	20	20
21	Peak growth	T2-T3	0	-1	-1	-2	1	-1	20	20
23	Peak growth	T2-T3	-2	1	-1	-1	0	-1	22	22
24	Peak growth	T2-T3	-2	1	-1	1	-1.5	-0.5	23	23.5
25	post peak	T2-T3	-1	2	1	-2	1	-1	26	24
27	post peak	T2-T3	-1	1	0	1	-1	0	27	27
28	post peak	T2-T3							28	28
29	post peak	T2-T3	-4	-0.5	-4.5	1	-2	-1	24.5	28
30	post peak	T2-T3	1	-2	-1	0.5	-0.5	0	29	30
31	post peak	T2-T3	0	1	1	0.5	1	1.5	32	32.5
32	Peak growth	T2-T3	-0.5	-0.5	-1	1	-0.5	0.5	31	32.5
33	Peak growth	T2-T3	-1.5	0.5	-1	-0.5	1	0.5	32	33.5
34	post peak	T2-T3	1.5	2	3.5	0	2	2	37.5	36
35	post peak	T2-T3	-1	-1	-2	-0.5	-1	-1.5	33	33.5
36	Peak growth	T2-T3	0	-1	-1	0	-1	0	35	36
37	post peak	T2-T3	-2	0	-2	0	-1	-1	35	36
38	Peak growth	T2-T3	-1	1	0	-1	1	0	38	38
40	pre-peak	T2-T3	-1	-1	-2	0	0	0	38	40
41	Peak growth	T2-T3	-2	0	-2	0	-1	-1	39	40
42	post peak	T2-T3	-2	-1	-3	-2	0	-2	39	40
43	pre-peak	T2-T3	-2	3	1	0.5	2.5	3	44	46
44	pre-peak	T2-T3	-3	1	-2	-1	0.5	-0.5	42	43.5
45	post peak	T2-T3	-1	1	0	0.5	1	1.5	45	46.5
46	pre-peak	T2-T3	-3	3	0	0	0.5	0.5	46	46.5
47	post peak	T2-T3	-0.5	0.5	0	-3	0.5	-2.5	47	44.5
48	post peak	T2-T3	0	-1	-1	0.5	-1	-0.5	47	47.5
49	Peak growth	T2-T3	0	2	2	-1	2.5	1.5	51	50.5
50	Peak growth	T2-T3	-1	0	-1	-1	1	0	49	50
51	Peak growth	T2-T3	-2.5	1	-1.5	0	-1	-1	49.5	50
52	Peak growth	T2-T3	-2	-1.5	-3.5	-0.5	-2	-2.5	48.5	49.5
53	Peak growth	T2-T3	-0.5	1.5	1	1	1	2	54	55
54	Peak growth	T2-T3	-2	2	0	1	0	1	54	55
55	Peak growth	T2-T3	-0.5	0.5	0	1	1.5	2.5	55	57.5
56	post peak	T2-T3	-1	-2	-3	-1	-1	-2	53	54
57	post peak	T2-T3	1	-0.25	0.75	-1	0	-1	57.75	56
58	Peak growth	T2-T3	-2	-0.5	-2.5	-1	0	-1	55.5	57
59	Peak growth	T2-T3	-1	0	-1	-0.5	-2	-2.5	58	56.5

Dental Rotational Changes:

Patient ID#	Growth status	Timepoint	Occ Plane (degrees)	U1 Tip(degrees)	U6 Tip(degrees)	L1 Tip(degrees)	L6 Tip(degrees)
1	Peak growth	T0-T1	1.5	-11.5	-4.5	8	-5
2	Peak growth	T0-T1	-2	-12	-4.5	7	-5
3	post peak	T0-T1	0	-2	-4.5	8	3
4	Peak growth	T0-T1	3.5	-3	-4	-6	0
5	post peak	T0-T1	2	2	3	3	4
7	Peak growth	T0-T1	0	-1	6	9	4.5
8	pre-peak	T0-T1	-1.5	1	0	15	-2
9	post peak	T0-T1	-2	-12	5	-7	-9
10	Peak growth	T0-T1	2	2	-9	-3	-1.5
12	Peak growth	T0-T1	1	-6.5	-3	-4	-11
13	pre-peak	T0-T1	3	2	-3.5	1	-2
14	post peak	T0-T1	3	3	-8	4	-5
15	Peak growth	T0-T1	5	-13	-5	0.5	-3
16	pre-peak	T0-T1	1	-1.5	-10	6	3
17	Peak growth	T0-T1	0	4	-7	3.5	-6
18	post peak	T0-T1	3	9	0	-5	-3
19	post peak	T0-T1	1	6	-8	-6	0
20	post peak	T0-T1	-1	10	-3.5	-1	0
21	Peak growth	T0-T1	5	2	-6	4	-4
23	Peak growth	T0-T1	-2	-1	5	-6	-2
24	Peak growth	T0-T1	6	3	-10	-1	-2
25	post peak	T0-T1	2	-3	8	-6	7
27	post peak	T0-T1	1	8.5	-2	-6	-1
28	post peak	T0-T1	2	-2	0	-5	0
29	post peak	T0-T1	-2	11	-3.5	7	-4
30	post peak	T0-T1	3	4	-2	2	-2
31	post peak	T0-T1	4	-7	-7	3	-4
32	Peak growth	T0-T1	-2	-6	-7	-3	0
33	Peak growth	T0-T1	5	-10	-5	9	-7
34	post peak	T0-T1	4	-3	-2	1	1
35	post peak	T0-T1	3	4.5	-2	5	-7
36	Peak growth	T0-T1	5	5	-3	7	1
37	post peak	T0-T1	1	-12	0	5	6
38	Peak growth	T0-T1	3.5	-4	-6.5	3.5	-5
40	pre-peak	T0-T1	8	-1.5	-6	5	-8
41	Peak growth	T0-T1	3.5	0	-2	4	-5
42	post peak	T0-T1	8	0	-3	7	-1
43	pre-peak	T0-T1	1.5	-5	5	7	-3
44	pre-peak	T0-T1	1	-10	-9	4	-6
45	post peak	T0-T1	4	-25	-5	4	-4
46	pre-peak	T0-T1	-3	12.5	3	5	-8
47	post peak	T0-T1	4	8	-11	5	-5
48	post peak	T0-T1	3	9	-3	0	-9
49	Peak growth	T0-T1	-5	6	0	5	-8.5
50	Peak growth	T0-T1	5	-7	-9	6	-3
51	Peak growth	T0-T1	6	3	-1.5	-2	-5
52	Peak growth	T0-T1	-3	-25	-4	15	-3
53	Peak growth	T0-T1	-2	14	2	-1	-6
54	Peak growth	T0-T1	4	-4	-2	3.5	0
55	Peak growth	T0-T1	6	-12	-10	5	-10
56	post peak	T0-T1	-1.5	-2	-1	9	-6
57	post peak	T0-T1	2	-15	-3	-2	-4.5
58	Peak growth	T0-T1	4.5	5	-5	2.5	-5
59	Peak growth	T0-T1	7	0	-8	7	-8

Patient ID#	Growth status	Timepoint	Occ Plane (degrees)	U1 Tip(degrees)	U6 Tip(degrees)	L1 Tip(degrees)	L6 Tip(degrees)
1	Peak growth	T1-T-2	2	8	1	4	1
2	Peak growth	T1-T-2	-2	-3	3	2	1.5
3	post peak	T1-T-2	1.5	3	4	0	3
4	Peak growth	T1-T-2	-1	-1	3.5	6	2
5	post peak	T1-T-2	-4	5	3	6	4
7	Peak growth	T1-T-2	2	2	4	3	2.5
8	pre-peak	T1-T-2	-2	10	4	9	5
9	post peak	T1-T-2	-7	3	6.5	14	9
10	Peak growth	T1-T-2	-5	15	12	10	10
12	Peak growth	T1-T-2	2	10	0	4	4
13	pre-peak	T1-T-2	-8	3	6	11	6
14	post peak	T1-T-2	-3.5	0	2	11	5
15	Peak growth	T1-T-2	-4.5	12	3	7	6
16	pre-peak	T1-T-2	-4	5	10.5	9.5	2
17	Peak growth	T1-T-2	-1	3.5	-4	10	4
18	post peak	T1-T-2	-9	7	6	7.5	7
19	post peak	T1-T-2	-1	5.5	7	2	3
20	post peak	T1-T-2	1	6	2.5	6	5
21	Peak growth	T1-T-2	-4	2	-1	-1	0
23	Peak growth	T1-T-2	2	0	5	6	1
24	Peak growth	T1-T-2	-5	5	5	7	-2
25	post peak	T1-T-2	-10	9	-2	7	-3.5
27	post peak	T1-T-2	-1	7.5	6	9	4
28	post peak	T1-T-2	-1	3.5	2.5	5	7
29	post peak	T1-T-2	-8	4	8	10	3
30	post peak	T1-T-2	2	0	-4	1	0
31	post peak	T1-T-2	-1	-4	1	3.5	0
32	Peak growth	T1-T-2	-3	5	2	2	2
33	Peak growth	T1-T-2	0	5	6	11	10
34	post peak	T1-T-2	-2	-1	0	2	5
35	post peak	T1-T-2	-2	10	7	10	5
36	Peak growth	T1-T-2	-6	15	3	9	8
37	post peak	T1-T-2	-3.5	1	0	6	5
38	Peak growth	T1-T-2	-3	2	3	5	6
40	pre-peak	T1-T-2	-5	0	1	1	1
41	Peak growth	T1-T-2	0	2	1.5	8	8
42	post peak	T1-T-2	-4	3	7	9	11
43	pre-peak	T1-T-2	1	1	-1	4	0
44	pre-peak	T1-T-2	-3	5	9	6	5.5
45	post peak	T1-T-2	-2.5	12	-3	1	0
46	pre-peak	T1-T-2	1	0	0	3	4
47	post peak	T1-T-2	-2.5	1.5	1	15	-3
48	post peak	T1-T-2	2	2	1.5	6	3
49	Peak growth	T1-T-2	-3	-2	9	7.5	5
50	Peak growth	T1-T-2	-4	3.5	4.5	7	8
51	Peak growth	T1-T-2	-4	1	4	2	8
52	Peak growth	T1-T-2	-6	5	9.8	10	5
53	Peak growth	T1-T-2	-9	4	-1	7	-3
54	Peak growth	T1-T-2	-1	3	9	5	-1
55	Peak growth	T1-T-2	-3.5	-1	2	5	0
56	post peak	T1-T-2	2	9	1	3	5
57	post peak	T1-T-2	-6	5	3	7	5
58	Peak growth	T1-T-2	-9	9	9	9	8
59	Peak growth	T1-T-2	0	6	2	9	4

Patient ID#	Growth status	Timepoint	Occ Plane (degrees) + counterclockwise/ - clockwise	U1 Tip(degrees)	U6 Tip(degrees)	L1 Tip(degrees)	L6 Tip(degrees)
1	Peak growth	T2-T3	-3	-2.5	1.5	3	4
2	Peak growth	T2-T3	1	-3	-3	3	3
3	post peak	T2-T3	1.5	3	0	-3	-5
4	Peak growth	T2-T3	0.5	2	0	-4	-4
5	post peak	T2-T3	3.5	0	2	1	-3.5
7	Peak growth	T2-T3	-3	0	-2	-2.5	-6
8	pre-peak	T2-T3	2.5	-6	0	-6	-8
9	post peak	T2-T3	-1	3	6	-2	-6
10	Peak growth	T2-T3	3	-6	-6	-11	-7
12	Peak growth	T2-T3	2.5	-3	-2	0	0
13	pre-peak	T2-T3	5	0	-2	-4	0
14	post peak	T2-T3	0.5	4	3	-4	-0.5
15	Peak growth	T2-T3	1	0	6.5	0	5
16	pre-peak	T2-T3	0	0	-5	-4	-0.5
17	Peak growth	T2-T3	-3	1.5	10	1	-0.5
18	post peak	T2-T3	-0.5	-2	-3.5	-5	-5
19	post peak	T2-T3	-2	-9	4.5	3.5	6
20	post peak	T2-T3	0	1.5	-1	-8	0
21	Peak growth	T2-T3	0.5	-8	6	0	-0.5
23	Peak growth	T2-T3	-2	-2	-6	-5	1
24	Peak growth	T2-T3	1.5	-1	1	-8	-2
25	post peak	T2-T3	6	10	-2	-2	1
27	post peak	T2-T3	-1	-2	-3	2	-5
28	post peak	T2-T3					
29	post peak	T2-T3	5	0	-9	-10	-4
30	post peak	T2-T3	-0.5	-3	-3	-2	-2
31	post peak	T2-T3	-3	1	4	5.5	4
32	Peak growth	T2-T3	1	5	-3.5	-1.5	-2.5
33	Peak growth	T2-T3	-0.5	-5	-8	-3	-4
34	post peak	T2-T3	2	1	-3	5	0
35	post peak	T2-T3	1	-5	-4	-1	-1
36	Peak growth	T2-T3	3	-4	-2	-7	-8
37	post peak	T2-T3	-1	-7	1.5	-3	-10
38	Peak growth	T2-T3	-4	0	-3	-3.5	-5
40	pre-peak	T2-T3	-1	2	2	-3	-1.5
41	Peak growth	T2-T3	1	-1	2	-2.5	0
42	post peak	T2-T3	2	-8	-8	-2	-2
43	pre-peak	T2-T3	3.5	-4	0	9	-2.5
44	pre-peak	T2-T3	1.5	-5	-8	0	0
45	post peak	T2-T3	-3	-3	6	-1	3
46	pre-peak	T2-T3	2	1	-2	1	0
47	post peak	T2-T3	-1	-8	2	-6	3
48	post peak	T2-T3	3.5	0	6	-4	1
49	Peak growth	T2-T3	2	-1	2	5	-3
50	Peak growth	T2-T3	1.5	-5	4	-2	-2
51	Peak growth	T2-T3	5	-1	-4	-3	-5
52	Peak growth	T2-T3	5	-4	-5	-8	-6.5
53	Peak growth	T2-T3	8	8	4	3	4
54	Peak growth	T2-T3	0	3	-8	2	-2
55	Peak growth	T2-T3	1	2	6	1	0.5
56	post peak	T2-T3	-3.5	-2	4	-8	-5
57	post peak	T2-T3	7	-4	-2	3	-3.5
58	Peak growth	T2-T3	4	-3	-7	2	1
59	Peak growth	T2-T3	-2	-2	2	-4	0

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